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Bureau of Domestic Commerce

STAFF STUDY

National Water Assessment

AN ANALYSIS OF PRICE/COST SENSITIVITY OF WATER USE IN SELECTED MANUFACTURING INDUSTRIES

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This is a Bureau of Domestic Commerce Staff Study. The information contained herein should not be construed as Department of Commerce policy.

Bureau of Domestic Commerce

U.S. DEPARTMENT OF COMMERCE/Domestic and International Business Administration

National Water Assessment

AN ANALYSIS OF PRICE/COST SENSITIVITY OF WATER USE IN SELECTED MANUFACTURING INDUSTRIES

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Office of Business Research and Analysis
Bureau of Domestic Commerce
Domestic and International Business Administration
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Prepared for
The Water Resources Council

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Foreword

This report was prepared for and with partial funding from the Water Resources Council by the Water Resources and Engineering Program of the Construction and Forest Products Division for the 1975 National Water Assessment. It was prepared under the supervision of K. L. Kollar, program manager, by Robert Brewer and Patrick H. McAuley.

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EXECUTIVE SUMMARY

The goal of a pricing policy for water is to use the market mechanism to reconcile conflicting demands on limited water supplies. Theoretically, if demand for a commodity such as water exceeds supply, then an increase in the price of that commodity will reduce demand. A sufficiently high price would serve to allocate available supplies to the most productive users of water, thus reconciling the differences between supplies and overall demands.

Because of the impact such a policy could have on the National Water Assessment and a national planning strategy, the Water Resources Council has undertaken a major study of the subject. The study deals with the spectrum of users of water, including not only manufacturing, but also irrigated agriculture, electric power generation, residential water use, mining, and transportation. Studies of the various water uses have been made by member agencies, with coordination and partial funding provided by the Water Resources Council.

The involvement of the Department of Commerce is to determine the impacts that water pricing would have on manufacturers. An impact of major interest is the extent to which the volume of water intake would be reduced. Another important impact would be on manufacturing costs. Also of concern are possible side effects on the environment and employee safety.

The "price" of water is a term which does not yet have a universal definition. Many water users obtain water free of charge from wells, rivers, lakes, estuaries, and other sources. Others obtain water from public water systems and irrigation projects, and pay a charge to cover the costs of delivering intake and removing wastewater. The "price" of water, as the term is used by its advocates, would actually be a tax levied upon the use of water. Whether this price would be based on the volume of intake or the volume of consumption is uncertain. For this analysis it is assumed that the price would be based on the volume of intake, since consumption is extremely difficult to measure accurately.

About 90% of the water intake by industry is obtained directly from lakes, rivers, wells, or estuaries. There is generally no price charged for water intake in these cases. However, these self-supplied users of water incur substantial costs in pumping, intake treatment, within-plant handling and conditioning, wastewater treatment, and engineering overhead. If a price or tax were to be charged for water intake, it would be in addition to these other water-related costs.

To be of value for policy-making purposes, the analysis must deal with the expected business environment of the future. Of crucial concern is the impact of the Water Pollution Control Act Amendments of 1972 (PL 92-500) under which stringent effluent quality standards have been or will be promulgated. By 1983, all existing manufacturing operations must be utilizing the best available technology to treat their effluents before discharge from the plant site. This will increase significantly the total costs of the water used in the plant. The imposition of a price for water withdrawn adds to those total water costs which we have assumed that a prudent manufacturer would strive to minimize.

The determination of minimum total water cost levels is complex decisions for each manufacturer that involve physical and chemical constraints as well as cost factors. To simulate the decision making processes we have developed mathematical models of four selected examples of manufacturing operations which are representative of the major water use elements in the manufacturing sector. The models are described in detail in following pages of this report.

The study assesses the impacts on hypothetical new plants employing current manufacturing technologies, the so-called, "green fields plants," thus allowing water uses and cost information to be developed on a design basis. It is probable, then, that the alternatives of cost management considered for these hypothetical plants may not be applicable for existing plants where the difficulties encountered in retrofitting and spacing of equipment and piping would greatly increase the costs over those developed for the study models.

It is assumed that manufacturing water users will have achieved compliance with Public Law 92-500 Effluent Limitations Guidelines as presently promulgated. This law requires that by 1983 the manufacturer provide "Best Available Treatment Economically Achievable." For most large manufacturing water users the least-cost method of meeting these strict requirements involves a high degree of within-plant reuse of treated and untreated wastewater instead of using water on a once-through basis. The cost savings, which are illustrated in this report, are so substantial as to induce water reuse to the highest optimum level. Thus, even in the absence of a price charged for water intake, recycling of treated effluents to optimum levels in the plants studied already have reduced intake by 59% to 97.5% of what would have been required if water had been used on a once-through basis. This study, therefore, focuses on the remaining 41% to 2.5%

Table 1 indicates the effect of PL 92-500 effluent quality standards on water use and water costs for the four simulated manufacturing operations. Water costs are shown for operations under conditions of the best available treatment of effluents. Also shown are the percentages of intake water that is replaced by recycled effluents under both conditions. In each case, it is assumed that no price is charged for raw water intake. It can be seen that with best available treatment of wastewaters, the manufacturers will have reduced their water intakes to a fraction of that required if no pollution control were imposed, even if no price is charged for the water withdrawn.

Public Law 92-500 will make manufacturers much less sensitive to intake water prices since the cost-conscious manager of the manufacturing plant of the future will be employing all of the obvious methods of water conservation such as recycling as well as many of the not-so-obvious ones. The object of this study is to analyze the remaining options to further reduce water intake that the plant could take in response to water prices.

TABLE 1. Impact of Water Pollution Control Requirements on Water Costs and Recycling Rates

	Costs per 1000 gallons of gross water used		Recycled Water as Percentage of gross water used	
	No Pollution Control	Best Available Treatment	No Pollution Control	Best Available Treatments
Non-Contact Cooling System	$.045	$.070	0%	97.5%
Integrated Cotton Textile Mill	$.340	$.979	0%	58.9%
Unbleached Kraft Paper Mill	$.085	$.158	64.9%	93.0%
Basic Oxygen Steelmaking Operations	$.117	$.405	10.5%	92.6%

Notes:

1. These estimates are based on hypothetical plants developed for the Price/Cost Sensitivity Analysis. Because of widely varying circumstances in the manufacturing sector, many actual plants would experience different costs and recycling rates.

2. The "no pollution control" case assumes plant uses cost-minimizing practices without regard for environmental impact. In actual practice most plants provide some wastewater treatment despite the extra costs.

3. All of these impacts are in the absence of any "price" for water use.

The study of selected manufacturing water uses found that very high prices for intake water would have to be charged to induce further reductions in withdrawals. These prices would usually have to be in excess of $0.70 per 1000 gallons, or it would be more cost-effective to pay the price for water and continue to withdraw the same quantity as before.

In general the plants would be operating at very high recycling rates, even in the absence of a price for intake water. In those cases there is a very small wastewater discharge, which could not be recycled unless it received additional treatment at high cost to demineralize or desalinate the wastewater. The exception is textile finishing, in which recycling of wastewater is sharply limited by the traces of color in the final effluent. In the case of the textile mill a price of $0.28 per 1000 gallons could induce the mill to install an activated carbon system to remove color traces. This would enable our simulated mill to increase its recycling to 76% of the gross water demand, the point at which dissolved solids inhibit further recycling. To maximize recycling at 85% of the gross water demand, a price of $1.50 per 1000 gallons of intake may be necessary.

Intake water prices would result in substantial increases in plant operating costs, but these costs would not be unmanageable as a percentage of value of shipments. For example, in the paper mill producing 1000 tons per day of unbleached kraft linerboard, total daily water costs at a price of $1.50 per 1000 gallons intake would be $5,800. This daily cost of $5,800 translates into 3.0% of the value of shipments at $195 per ton of linerboard. A textile mill producing 35,000 pounds of printed cotton cloth would incur $660 daily in additional costs if a $1.50 price were charged for water. Given a value of $3.00 per pound of finished cloth, the extra cost is 0.7% of the value of shipments.

If the goal of intake water pricing is to allocate net demands on stream flow in a river basin, then recycling water within the plant does not further this objective, since its impact on consumption of water is negligible. Other methods of reducing intake besides recycling are analyzed in the following pages. In each case these alternatives were found to involve extremely high costs and/or new problems, such as environmental degradation and occupational safety hazards.

Although this analysis has concluded that water pricing would not result in significant water savings in most manufacturing situations, there are special cases where water prices could have the desired effect.

One special case involves plants which meet pollution control requirements by discharging wastewater into evaporative lagoons, rather than by treating and recycling it. Although such plant practices are not common, they are frequently applied in arid regions, where conservation of the scarce water resource would be most beneficial. In those cases a policy to establish prices for water intake at high enough levels to discourage the practice would make more water available for other users.

Another case in which the conclusions of this analysis might not apply would be if the plants in question were not self-supplied water users, but were purchasing water from a municipal system. If the goal of water pricing is to allocate demands on an overburdened public water system, then maximizing the within-plant recycling by manufacturers would be of some benefit. Of course, the water price would have to be very stiff to induce the manufacturer to install the necessary facilities.

It has been assumed in this study that there will be no modification of water pollution control goals of PL 92-500 which are expected to become mandatory over the next decade. If these goals are relaxed, then industrial plants would not generally treat and recycle wastewater to the higher levels assumed in this study. In that case, the current goals of PL 92-500 and conservation of water withdrawals could both be achieved through a pricing policy for water.

In general, the value of manufactured products is high relative to water costs, and with the manufacturers ability to pass on costs to customers, modest prices charged for water will have little effect on either product costs or water use beyond that already brought about by the increases in production costs associated with the effluent limitation guidelines.

ANALYSIS OF PRICE/COST SENSITIVITY OF SELECTED MANUFACTURERS WATER USES

Introduction

The sensitivity of manufacturers to water prices varies from plant to plant, due to factors such as size, age, location, source of water, manufacturing technologies, and costs of production. The wide diversity of the manufacturing sector requires that a rigorous analysis focus on specific examples of industrial water use. If these selected examples are typical, then conclusions can be made which apply to the manufacturing sector generally.

Four manufacturing water uses have been selected for analysis because they are major uses and are characteristic of the variety of situations that exist. These four examples are generally typical of the manufacturing sector in their sensitivity to water prices, given the assumptions stated below. The sensitivity of manufacturing water use to incremental price and cost changes is examined for sample categories of water use in these hypothetical situations:

1. Non-contract Cooling Water
2. Integrated Finished Cotton Textile Manufacture
3. Unbleached Kraft Paper Manufacture
4. Conversion of Iron to Steel

The non-contact cooling water use was selected because it is the largest use of water in manufacturing, accounting for nearly two thirds all water used. Non-contact cooling systems are widespread, being found in many industries.

The use of water in papermaking was selected because the paper industry is one of the most water-intensive of industries. The paper industry uses more process water than any other, and the wastewater is typical of industries with organic wastes. Only unbleached papermaking was considered because effluent limitation guidelines for paper bleaching had not been developed when this study was made.

Process water use in textile finishing was selected because it represents a difficult combination of colored wastewater and high quality requirements for intake water.

Water use in steelmaking was selected because of the huge volume of water used by the steel industry, and because the wastewater is similar to other industries which are high in inorganic wastes. This analysis deals only with those operations involved in the conversion of iron into steel ingots. Although this is only part of the activities of an integrated steel mill, the conclusions are applicable to most of the other operations as well.

The four cases which are analyzed in this study deal with hypothetical plants. They are synthesized from technical literature and from discussions with professionals involved in these operations. These hypothetical plants are assumed to be in the design stage at the time of the analysis. They are generally medium-sized operations using technology which is expected to be typical in the 1980's. These plants have wastewater treatment facilities that meet the pollution control standards mandated by the Public Law 92-500 for 1983 (Best Available Technology).

NON-CONTACT COOLING WATER

The U.S. manufacturing sector utilizes immense quantities of energy to transform chemically and physically its raw materials into the finished products of trade and commerce. In 1971, the last year for which information is available, the sector used fuels and electric energy equivalent to 3.847 trillion kilowatt-hours (3.847×10^{12}kwh). This was 39% of the total energy consumption in the U.S. Eventually, the laws of thermodynamics prevail and after its use the energy that is not bound up in the final products reverts to heat, the ultimate form of waste in any energy-using system.

The total heat value of the fuels and electric energy used by manufacturers in 1971 was equivalent to the heat content of about 500 million tons of coal, or about 13.1 quadrillion Btu's. (13.1×10^{15}Btu) It is doubtful that more than a tiny fraction becomes the binding energy of the final products. Therefore, essentially all becomes waste heat that must be dissipated within the general environment. While varying portions of the waste heat are dissipated by stacks, by air convection, and by radiation, efficiency in manufacturing operations requires that more rapid and effective methods of removal of waste heat and control of operating temperatures be employed. Water, because of its unique physical and chemical characteristics, is an excellent coolant, and it is that use which accounts for nearly 70 percent of the total water demand in manufacturing.

There are two major methods for employment of water as a coolant, commonly classified as contact, and non-contact cooling. In the first, contact-cooling, the water is used to quench the hot materials or products in emersion baths or sprays, by which methods the water absorbs or is polluted with organic and inorganic compounds in addition to heat.

The more common application of water as a coolant is in non-contact cooling, whereby the water is circulated through pipes, tubes, and jackets that physically separate the water from the materials or products to be cooled. Usually, the non-contact cooling water is circulated at high enough rates that the temperature of the water rises less than 25°F to assure that critical temperature ranges in the manufacturing processes are maintained, and to reduce heat stress on the cooling system.

In past years, when water was plentiful, manufacturers took their cooling water from a surface stream or lake, passed it once through the cooling system and returned the heated wastewater to the source. More recently, induced by environmental and economic considerations, manufacturers have employed recirculating cooling water systems in which the heated water is cooled by evaporation in cooling towers or ponds and returned to the system, rather than discharged.

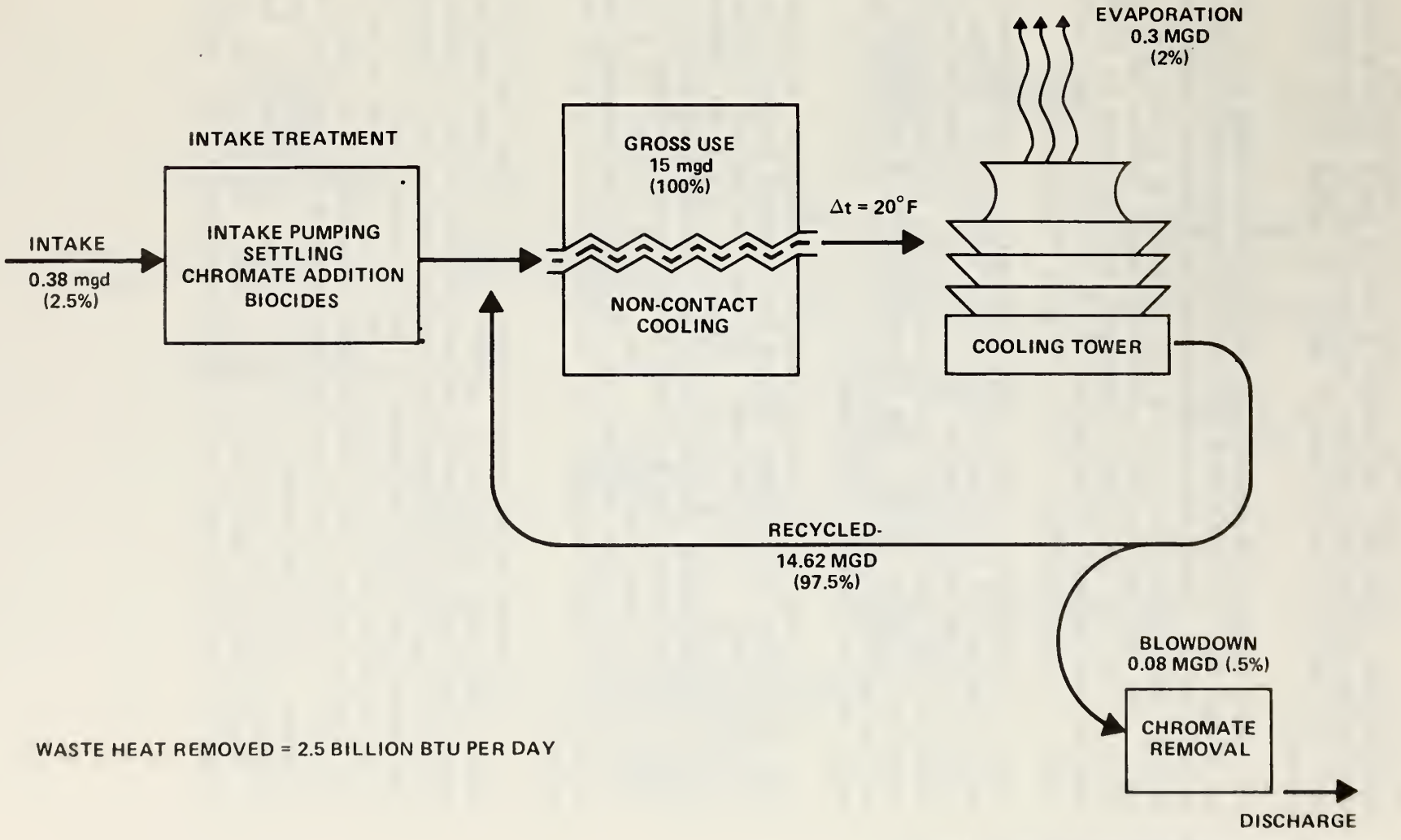
The Price/Cost Sensitivity Analysis is applied to the water demands for non-contact cooling at a hypothetical new manufacturing installation, thus avoiding the uncertainty of cost estimates for retrofitting that would be necessary if an existing installation had been assumed. Figure NC_1 is a schematic diagram of the simulated recirculating non-contact cooling system. Intake water is assumed to be withdrawn from a river or lake and required treatment by settling before use. Anti-corrosive agents and biocides are added to the system to control scaling, corrosion, and biological growths that might foul the heat exchanger surfaces and cooling tower.

Any water discharged from the system must meet water pollution control standards which require that these discharges be from the cold side of the cooling tower, and receive treatment to reduce the concentrations of heavy metal ions, biocides and other constituents to meet effluent limitation guidelines.

The simulated non-contact cooling water system has a flow-through rate of 15 million gallons per day (mgd) and absorbs 2.5 billion Btu's of heat per day, thus increasing the temperature of the cooling water 20°F. Current technology applied to reduce the temperature of the heated water so that it could be acceptable for either discharging or recycling is to employ evaporative cooling in induced-draft cooling towers or in large holding ponds. To cool the water 20°F in preparation for recycling, 2 percent of the volume of recirculating water must be evaporated. (See Appendix A for further explanation.)

If, following the cooling by evaporation, the remaining water is recycled with only the portion evaporated being replaced by new make-up water, the dissolved solids in the circulating water will become progressively more concentrated, causing severe problems of scaling and

Figure NC—1. **Model Non-Contact Cooling System**



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corrosion. The build-up of dissolved solids can be controlled, however, by drawing off a part of the circulating water for discharge, referred to as "blowdown," and increasing the volume of make-up water by a like amount.

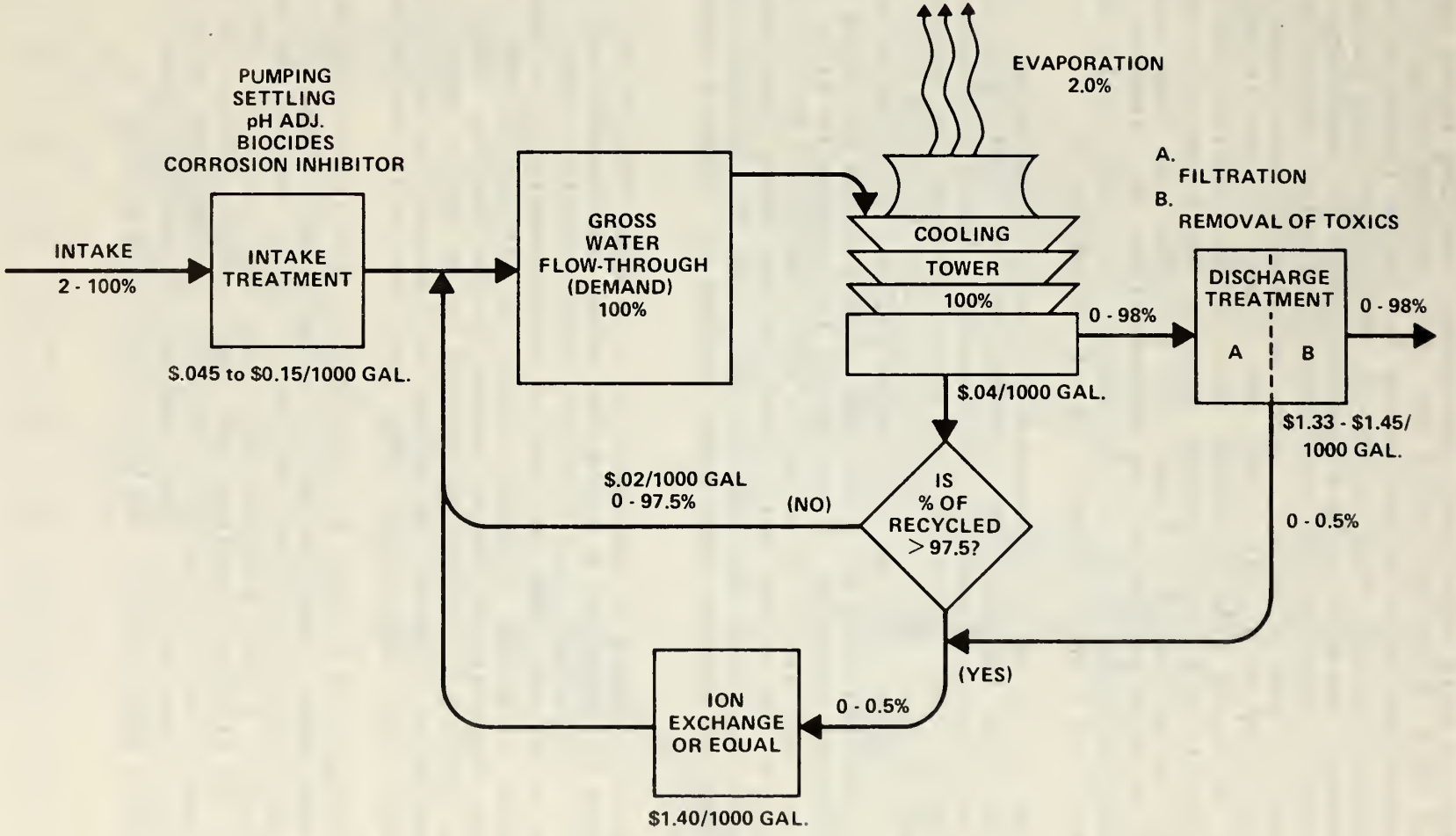
For this simulated water system it is assumed that make-up water has a dissolved solids concentration of 300 parts per million, and the maximum allowable dissolved solids concentration in the recirculating water is 1500 ppm. The system is thus operating at 5 cycles of concentration of the limiting dissolved solids, and an equilibrium can be maintained by blowdown of 0.5% of the recirculating water. (See Appendix A for further explanation.)

Since evaporative losses are 2 percent of the flow-through and blowdown is 0.5 percent in our simulated system, the make-up water volume must be at least 2.5 percent of the gross water demand, if 97.5 percent is to be provided by recycled water. Thus, the extent to which recycled water can be substituted for make-up water is limited by the evaporative losses and blowdown.

The Price/Cost Sensitivity Analysis attempts to determine how much more the intake might be reduced beyond 2.5 percent of gross use, if prices are charged for water intake, and at what price levels those reductions might be induced. For the simulated system utilizing an induced-draft cooling tower, evaporation is a fixed loss where recovery for recycling is not feasible. Only the blowdown, 0.5 percent of the total water volume, is amenable to recovery and reuse after demineralization for removal of its dissolved solids.

The price/cost sensitivity model calculates the total costs per 1000 gallons of gross water use that would be associated with different prices of raw water intake. Clearly, a price charged for water intake will increase the costs per 1000 gallons of gross water use. A method of minimizing the cost impact of water prices is to recycle the cooled water and thus reduce the amount of water intake needed. It is a complicated decision to determine the optimum recycling rate, involving cost trade-offs and physical/chemical constraints. These factors are summarized in figure NC-2, which is a flow-chart used to make the computer program for the cost/price sensitivity model.

Figure NC—2. **Decision Model For Non-Contact Cooling Water System — 10,000 GPM**



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The sensitivity of water withdrawals to prices is inelastic in this simulated non-contact cooling water system. Figure NC-3 shows the costs per 1000 gallons of gross water use associated with given prices for water intake at various recycling levels. The lowest point on each cost curve represents the most cost-effective level of recycling. It is readily apparent why the demand for intake water is inelastic in this system. Since the manufacturer would be recycling 97.5% of his gross use anyway, intake is only equal to about 2.5% of gross use. Prices charged for water withdrawals will not further improve recylcing rates unless the price is over $1.30 per 1000 gallons. At this price it would be more economical to demineralize the blowdown and recycle it rather than to discharge it. This would lower intake from 2.5% to about 2.0% of gross use.

A price of $1.30 per thousand gallons of intake may induce the plant to recycle the blowdown, but it would also have a major impact on water system costs. Table NC-1 shows the impact that water pricing would have on the hypothetical 15 mgd system. This $1.30 charge would increase water costs from $.070 to $.103 per thousand gallons of gross water use. The increased cost of $.033 per 1000 gallons of gross use would raise the cost of operating the system to $1545 per day, up from $1050 if no price were charged. The extra costs are due to the price paid for the water lost through evaporation, plus the cost of operating the blowdown demineralization system, less some savings in intake treatment costs.

One point should be emphasized. In this case the major impacts of charging a price for water withdrawals are to reduce withdrawals and increase manufacturing costs. This $1.30 price per 1000 gallons of intake would <u>not</u> reduce consumption of water, because recycling wastewater does not reduce evaporation, which occurs in the cooling tower. Since recycling reduces discharge by an amount equal to the reduction in intake, the effect of the cooling water system on water flow downstream from the plant would be unchanged.

If consumptive losses by evaporation are to be reduced or eliminated, some method of cooling other than evaporative cooling towers would be required. Two alternatives are suggested, direct air cooling, and "dry" cooling towers. There is little operating and cost data to enable the testing of these alternatives by price/cost sensitivity analysis, and there are serious questions as to the universality of their applications in industrial operations.

Figure NC—3. **Cost Effectiveness Of Cooling Water Recycling Under P.L. 92-500 Effluent Limitations Constraints**

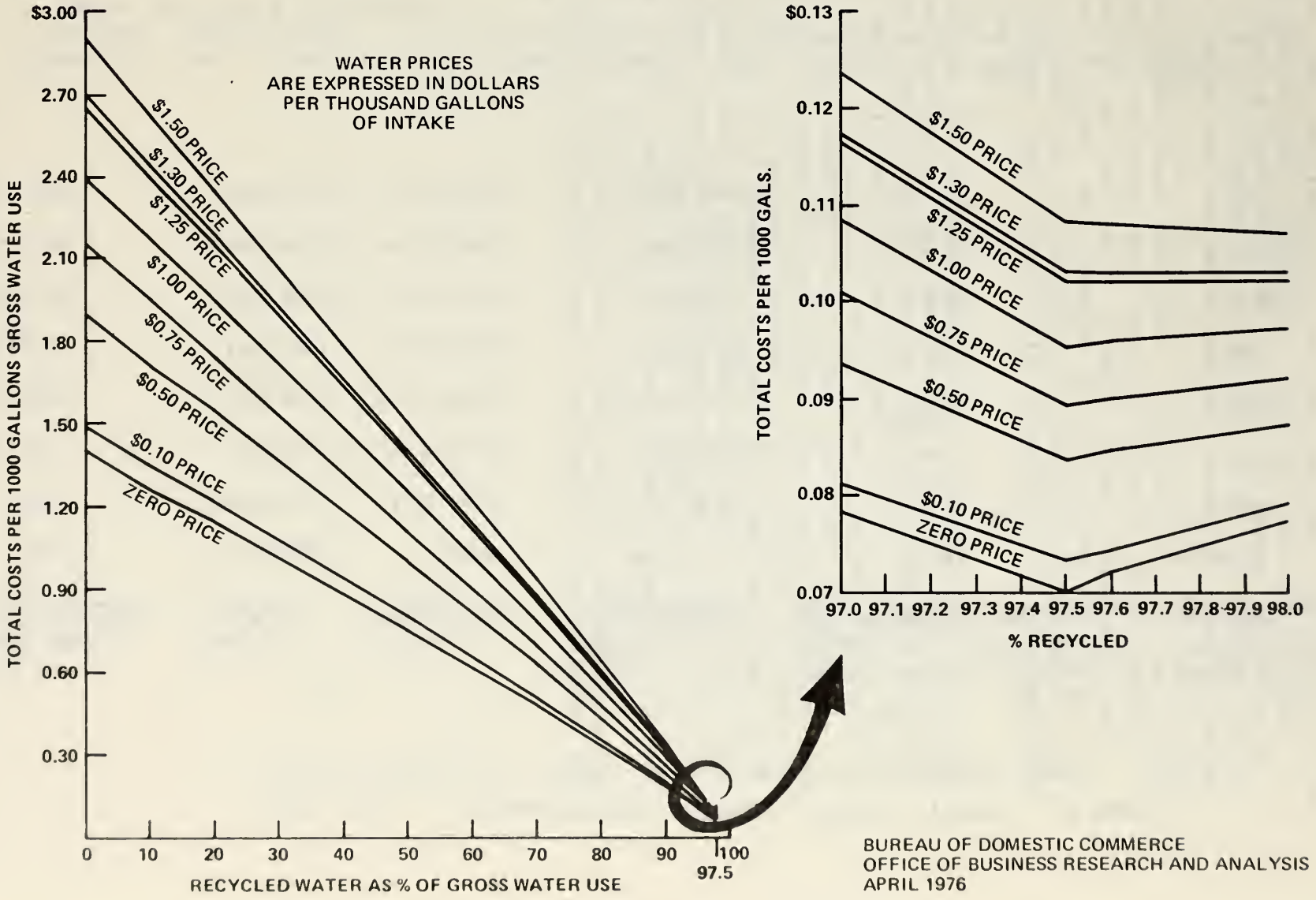

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Table NC-1. SIMULATED NON-CONTACT COOLING SYSTEM (15 mgd)
Plant Operating at Most Cost-Effective Recycling Level

Price of Intake Water (per 1000 gal)	Water Intake	Water Recycled	Water Consumption	Total Water-related Costs per 1000 gal of Gross Water Use	Total Water-related Costs per day
0¢ *	15.0 mgd	0 mgd	**	$.045	$675
0¢	.375 mgd	14.6 mgd	.300 mgd	$.070	$1050
$.10	.375 mgd	14.6 mgd	.300 mgd	$.073	$1095
$.50	.375 mgd	14.6 mgd	.300 mgd	$.083	$1245
$1.00	.375 mgd	14.6 mgd	.300 mgd	$.095	$1425
$1.25	.375 mgd	14.6 mgd	.300 mgd	$.102	$1530
$1.30	.300 mgd	14.7 mgd	.300 mgd	$.103	$1545
$1.50	.300 mgd	14.7 mgd	.300 mgd	$.107	$1605

*Special Case. Costs and recycling practice indicated in the absence of water pollution control requirements. All other cases assume plant is meeting PL 92-500 standards. (Best Available Technology)

**Consumption in once-through cooling systems without cooling towers or lagoons occurs after discharge and is dependant upon the nature of the receiving body of water.

Direct air cooling is used for industrial air conditioning, stand-by power generation, gas compressors, hydrocarbon condensing, and similar applications, but has not proved to be practical for most industrial applications where large quantities of heat must be removed, or where temperatures must be controlled within a narrow range. The capacity of air to remove heat is considerably less than that of water, 3300 cubic feet of air being required where one cubic foot of water would have sufficed. Utilizing air as the coolant for large industrial heat removal demands, then, would require the movement of a tornado of air through a vast network of ducts, accompanied by high noise levels and large thermal air currents in the nearby environment. It would appear, then,, that this alternative is unacceptable for general use.

Dry cooling towers use water as the coolant, but replace the evaporative cooling tower with a heat transfer device similar in principle to the automobile radiator. Since water is still used as the primary coolant, many of the limitations of direct air cooling are avoided. From the limited data available, dry tower costs are very high, probably one order of magnitude higher than the equivalent wet tower. Preliminary studies of dry cooling towers at the University of Houston suggest that for the simulated non-contact cooling water demand of 15 mgd assumed in the Price/Cost Sensitivity Analysis, a price or tax of $4.00 per thousand gallons may induce a shift to dry cooling. Probably the greatest constraint to the widespread use of dry cooling towers is the environmental and aesthetic objections that would arise. They would be large structures, operating at high noise levels, emitting large volumes of heated air.

Cotton Textile Finishing Process Water

The textile industry provides the fabrics from which clothing, drapery, upholstery, and numerous other products are made. Over 900,000 Americans are employed by this labor-intensive industry. Another 1.3 million workers are employed by the apparel industry, the largest user of textiles.

Textile manufacture involves three major stages:

(1) Spinning fibers into yarn

(2) Weaving or knitting yarn into cloth

(3) Finishing raw cloth into dyed or printed fabric

The first two stages include the more labor-intensive operations in textile manufacture. The finishing stage includes the more automated process operations. It is in the finishing of textiles that 95% or more of the process water is used.

The fibers used to make textiles may be cotton, wool, man-made, or blends of these. Although synthetics now account for more than half the total fiber consumption, there are numerous types of synthetic fibers such as rayon, acetate, and polyesters. Cotton is the most common single fiber used in textile making.

Over 7200 establishments are classified as textile mills, of which 788 withdraw more than 20 million gallons per year. The total gross water use of these 788 textile mills is 426 billion gallons per year. This volume of water is small compared to the largest water-using industries, but the number of plants withdrawing over 20 million gallons annually is considerable. In parts of the Southeast, where the industry is concentrated, textile mills are among the largest water using industries.

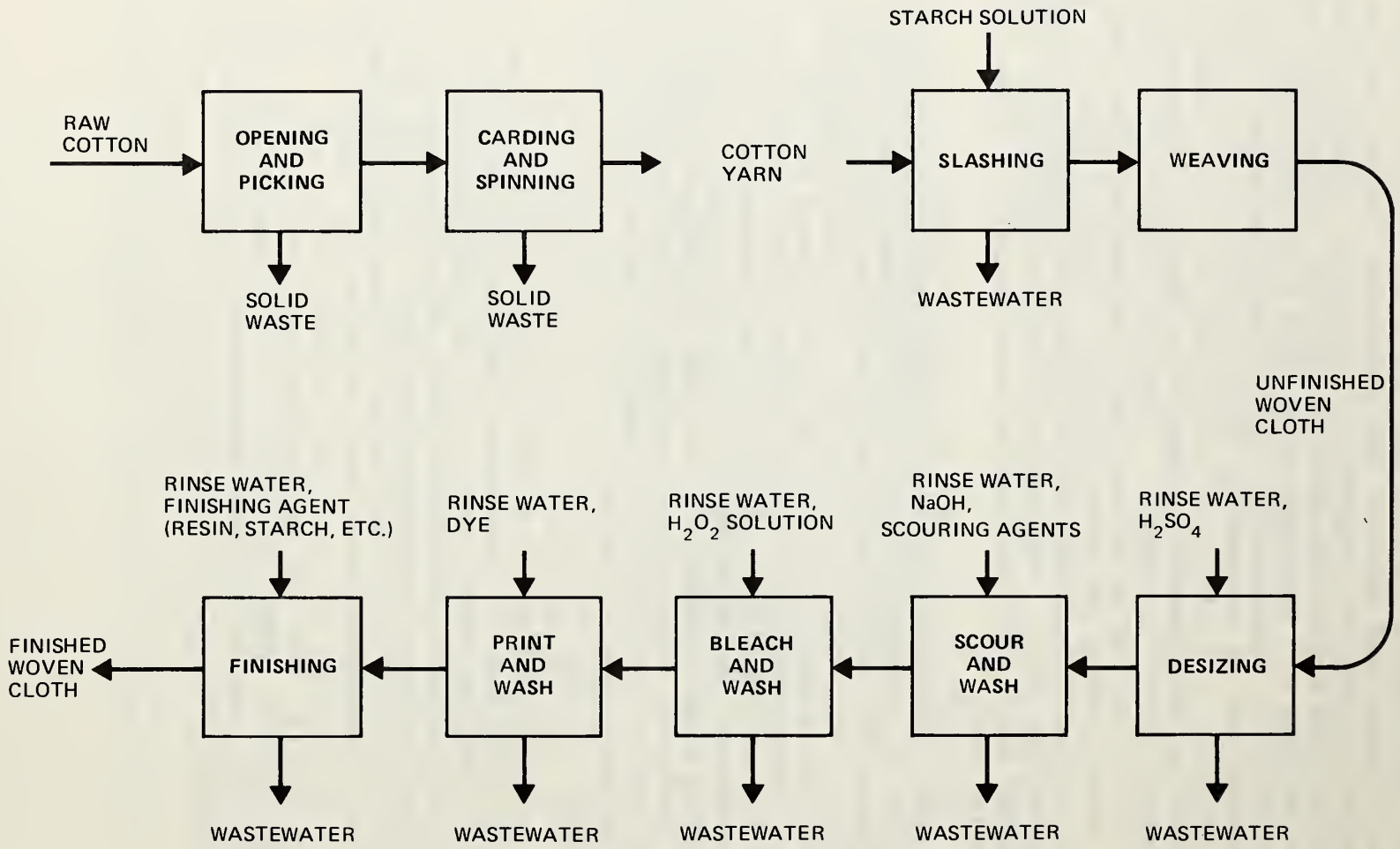
About 65% of the water intake of the textile industry is self-supplied, chiefly from surface sources. The remaining 35% is supplied by municipal water systems. For the manufacturing sector as a whole, only 11% of water intake comes from municipal water systems. The fact that this ratio is relatively high for textile manufacture is a reflection of the relatively small size of these mills.

Nearly half of the gross water use of the textile industry is for air conditioning. About 35% of gross use is for process uses, and most of the remainder is for sanitary purposes and boiler feedwater. However, process water accounts for about 70% of water intake, compared to less than 30% for air conditioning. The air conditioning use of water is a specialized form of non-contact cooling, characterized by unusually high recycling rates. Air conditioning results in a relatively low heat absorption per gallon of throughput, and as a result, evaporation and blowdown losses are small. Some air conditioning systems use "dry" cooling towers rather than evaporative towers, and water losses are even smaller. Process water is much more difficult to recycle, and has a considerably higher consumption rate. The intake of water for process use, totaling about 125 billion gallons in 1973, is the focus of this study.

For the Price/Cost Sensitivity Analysis of process water demands in cotton textile finishing, conditions are simulated for a typical textile mill producing 35,000 pounds of finished cloth per day, with an average process water requirement of 1.235 million gallons per day. It is an integrated mill; that is, the plant operations begin with raw cotton fiber which is spun, woven, and dyed or printed into finished colored or printed cloth. As can be inferred from Figure T-1, a number of process operations are involved. It is essentially a "batch" operation in which the materials receive special processing and finishing to customers specifications, after which other batches follow.

In the simulated textile mill, water withdrawn from a river is treated prior to its use as process water by settling, coagulation, and filtration. It is then applied in the various operations with additions of sizing agents, acids, alkalies, enzymes, bleaches, and dyes. In some of the operations, the water is heated to near boiling temperature, and as a consequence evaporative losses of water average about 15 percent of the total process water use. The waste waters from the operations are high in biochemical oxygen demand (BOD), suspended solids, and color. In addition, some of the effluent streams are scalding hot, and others are acidic or alkaline.

Figure T—1. **Process Flow - Integrated Cotton Textile Mill**



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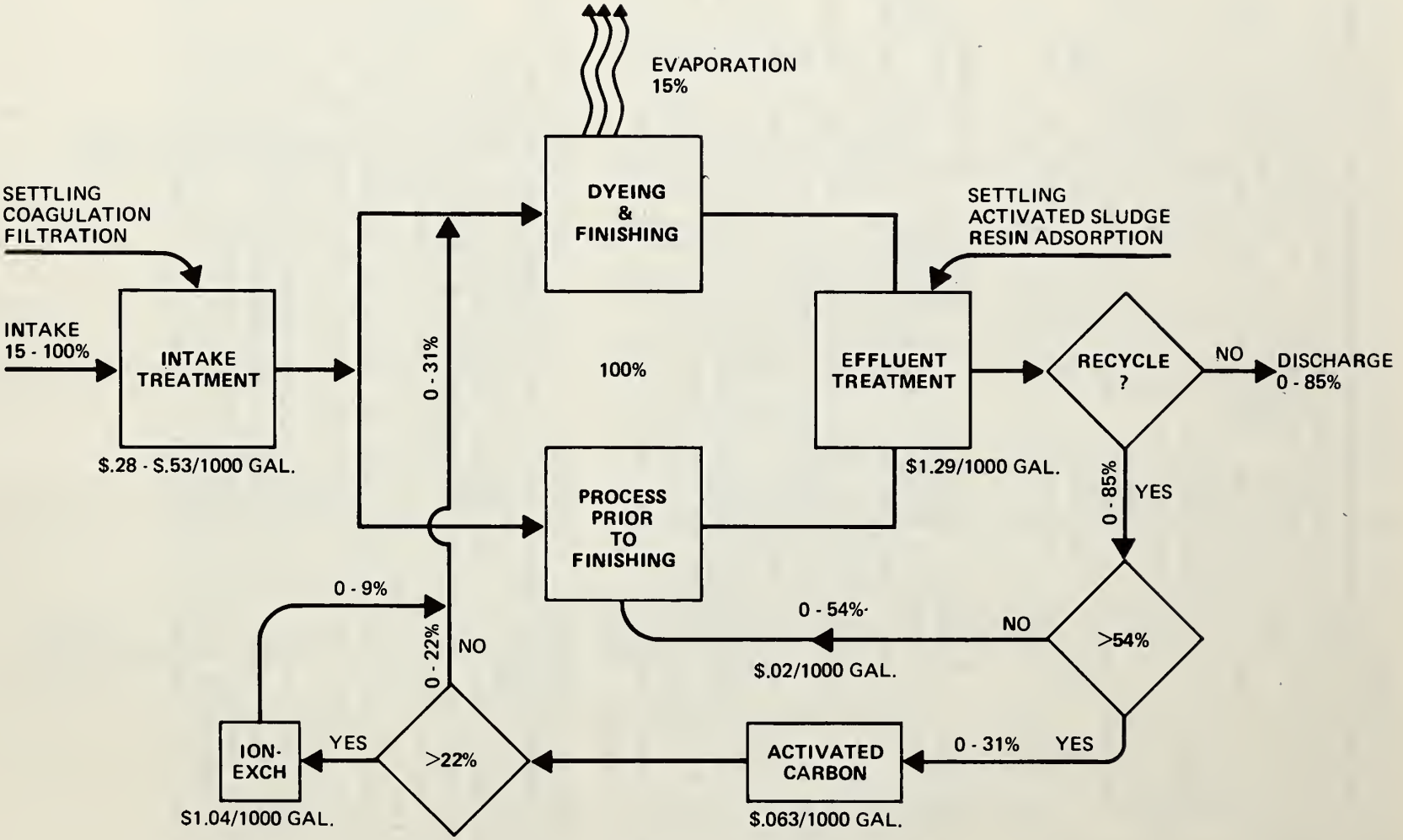
It is assumed that the textile mill has installed and is operating pollution control facilities in full compliance with the EPA effluent limitation guidelines for best available treatment technology, as depicted in Figure T-2. The high-quality treated effluent is suitable for reuse in many of the manufacturing operations. It can be seen from Figures T-2 and T-3 that it is cost effective to substitute the treated effluent for new intake for 54 percent of the process water demands even at zero price for raw water withdrawn. The major inhibitor to further recycling is the stringent quality requirements for water used in the dyeing and final rinses. The effluent from the wastewater treatment plant is not of high enough quality to recycle for these uses.

However, if this effluent were to receive additional treatment by carbon adsorption an additional 22 percent could be recycled to the dyeing and final washes. There would still be 9 percent that would have to be discharged as "blowdown" to prevent the build-up of dissolved solids in the recirculating water from reaching unacceptable levels. If the remaining 9 percent were to be demineralized by dual-bed ion-exchange, reverse-osmosis, or similar technologies, then it too could be recycled. This last step would approximate zero discharge from the textile mill. However, because about 15 percent of the water circulating in the mill is lost by evaporation, the withdrawal requirements cannot be reduced below 248,000 gallons per day.

Advanced treatment technologies such as carbon adsorption and ion-exchange are costly, and a cost-minimizing manufacturer would not normally employ them if his plant effluents were in compliance with pollution control regulations. This is illustrated in Figure T-3, a set of curves developed by the price/cost sensitivity model, relating total water costs to the percentage of recycled treated effluents employed at various imposed water prices. At any given price the low point of the curve is at the intersection of the least total water cost and the optimum recycling level. It can be seen that with zero price for water, the mill would recycle treated effluents equivalent to 48 percent of its gross water demand. A price of 10¢ per thousand gallons would increase total water costs, but would not induce additional recycling. Not until a price

Figure T—2. Decision Model For Cotton Textile Finishing-Process Water



FLOWS ARE IN % OF GROSS WATER DEMAND OF 1.235 MGD.

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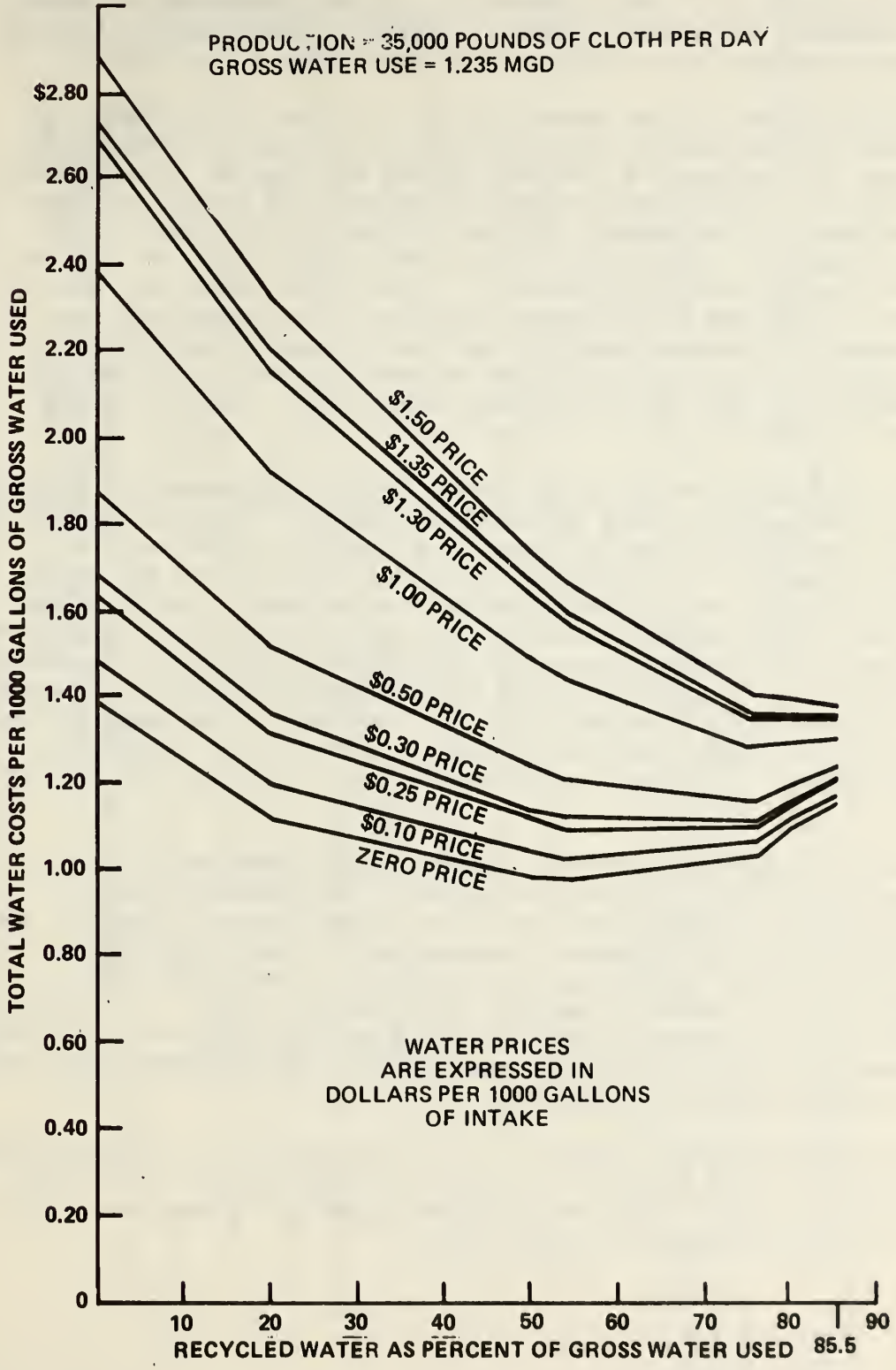
Figure T—3 **Cost-Effectiveness Of Recycling Process Water In The Hypothetical Textile Mill**



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of 28¢ per thousand gallons were assessed would it become cost effective to install carbon adsorption treatment and increase recycling to 76 percent of the gross demand. Progressively higher prices would not influence additional recycling until a level above $1.32 per thousand gallons was reached, at which price it would become cost-effective to demineralize and recycle the remaining 9 percent.

Although there is the possibility in this simulated mill of reducing intake from 46 percent of gross demand to 15 percent by charging a "stiff" price for water, the benefit of this as a resource conservation tool is questionable. The effect of increased prices and costs of water would be to increase recycling within the plant, not to reduce the volume of water consumed. This means that the net effect on stream flow below the plant is unchanged, and the impact on water quality in the stream would probably be minimal. The major effect of such a tax would be to increase the cost of producing textiles. This is illustrated in Table T-1.

Use of solvents other than water could considerably reduce water intake, but this appears unlikely. Serious study of textile processing with organic solvents dates back at least 15 years, although special finishing such as water repellants has been practiced for more than a generation. The most advantageous substitutes are chlorinated solvents such as perchloroethylene and trichloroethylene. Suitable machines can be manufactured and operated so as to control air pollution in the work space. Solvent loss remains an economic problem. Extremely tight control is needed to keep solvent loss per operation below 5 percent of fabric weight.

To date, there has been no appreciable commercial use of solvent finishing for woven goods. Very substantial research and development over the last decade have not led to replacement of aqueous processing to any appreciable extent. Of the thousands of different dyestuffs and chemicals now used in textile processing, only a limited number can be transferred directly to solvent use. Solvent processing would therefore necessitate a complete line of textile processing compounds.

On the grounds noted above, it is concluded that alternative solvents are not likely to replace water unless they lead to better quality fabrics or have superior characteristics in certain processing operations.

Table T-1

EFFECTS OF WATER PRICING ON THE SIMULATED TEXTILE MILL*

Price	Intake	Recycled	Consumption	Water costs per day	Water Costs per 1000 gal. of gross use	Water Costs per pound of textiles	Water Costs as percent of value of production
0**	1.24 mgd	0	.19 mgd	$421	$.34	$.012	0.4%
0	.57 mgd	.67 mgd	.19 mgd	$1214	$.98	$.035	1.1%
$.10	.57 mgd	.67 mgd	.19 mgd	$1271	$1.02	$.036	1.2%
$.28	.30 mgd	.94 mgd	.19 mgd	$1368	$1.10	$.039	1.3%
$.50	.30 mgd	.94 mgd	.19 mgd	$1433	$1.16	$.041	1.4%
$1.00	.30 mgd	.94 mgd	.19 mgd	$1582	$1.28	$.045	1.5%
$1.32	.19 mgd	1.05 mgd	.19 mgd	$1675	$1.35	$.048	1.6%
$1.50	.19 mgd	1.05 mgd	.19 mgd	$1707	$1.38	$.049	1.6%

*Cost estimates based on March 1975 prices
Gross Water Use = 1.235 million gallons per day
Price of Finished Cloth = $3.00 per pound
Production of Mill = 35,000 pounds per day

**Special Case. Costs and recycling practices indicated in the absence of water pollution control requirements. All other cases assume plant is meeting Public Law 92-500 effluent standards. (Best Available Technology).

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WATER USE IN PAPERMAKING

The U.S. Pulp and Paper Industry produced about 55 million tons of paper and paperboard in 1975, of which about 35 million tons were produced by the kraft process. Water is a basic input into more than 20 operations in the kraft papermaking process. Since large volumes of water are needed, the majority of paper mills are located adjacent to lakes or rivers capable of satisfying these needs. A typical plant may require in excess of 80,000 gallons of water per ton of paper produced, but as a general practice, for economic as well as environmental reasons, water is reused and recycled in the mills, thus reducing the withdrawals to a fraction of the gross water demand.

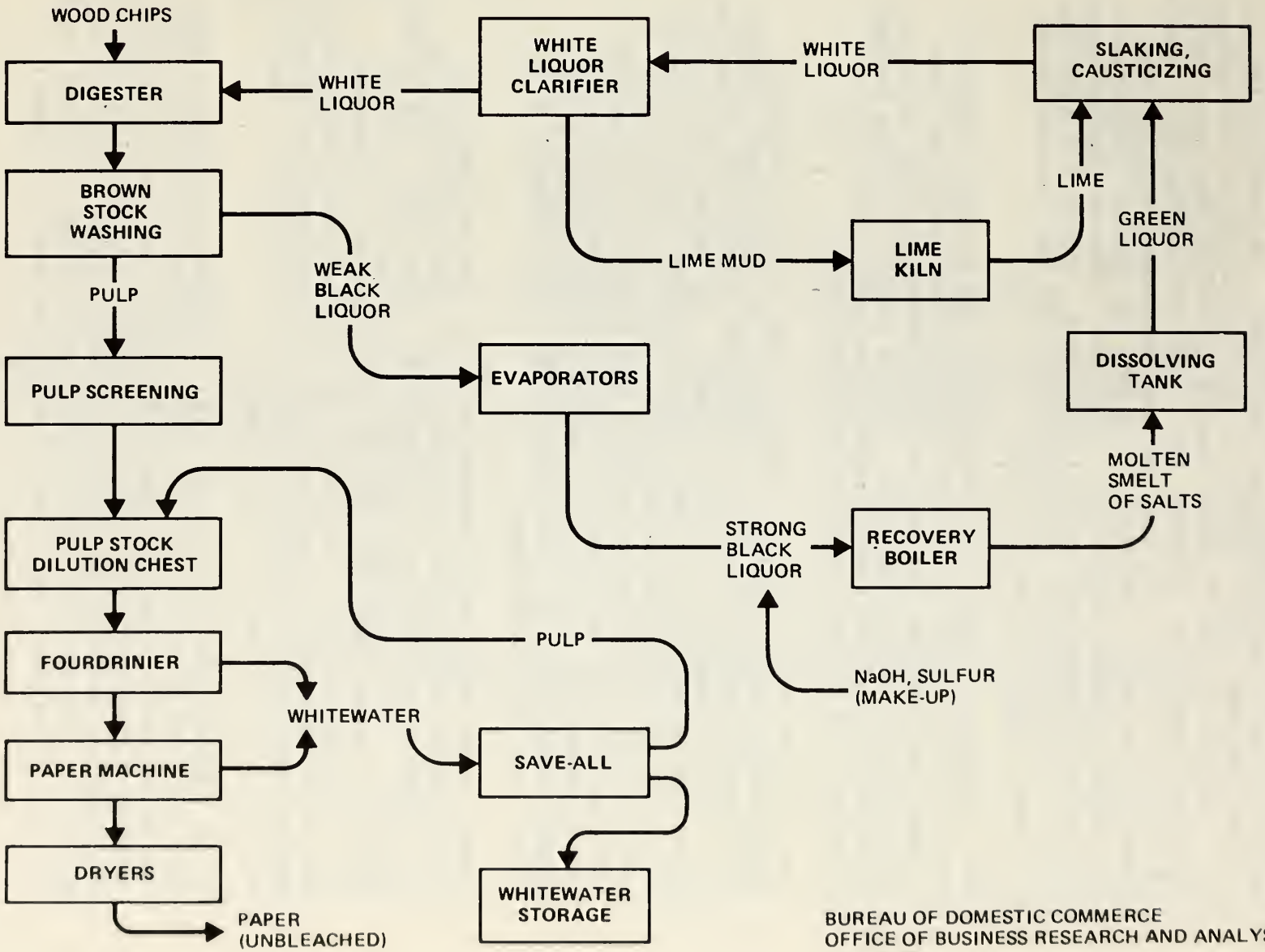
The kraft papermaking process is a complicated series of physical and chemical operations involving extensive automation for process and quality control. The basic operations involve the reduction of logs into wood chips, the washing of the fibers and suspension in "stockwater," the drying of the fibers to form sheets of paper, and the recovery of fibers in wash waters. (Technically, the term "kraft" refers to paper and paperboard manufactured using the sulfate pulping process, but it is common to refer to these pulping and byproduct recovery operations as the kraft process.)

Included along with those basic operations are by-products recovery, the recovery and regeneration of spent chemicals, and the recovery of energy from vapors and from the combustion of liquid and solid wastes. The later steps are critical to the economics of the kraft process. Figure K-1 is a simplified diagram of the combined operations.

Description of Hypothetical Kraft Unbleached Paper Mill

For the Price/Cost Sensitivity Analysis, a hypothetical, integrated kraft paper mill producing 1000 tons per day of unbleached linerboard from woodchips is selected. Although paper mills of this size often have combined steam electric power plants and process steam generating stations, the water use in those facilities is not included in the analysis. The focus of the analysis is on the process water demands and on the water used for non-contact cooling and condensing in process operations.

Figure K—1. **Process Flows In Kraft Paper Making (Greatly Simplified)**



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In the hypothetical plant, total process water demands are 63.8 million gallons per day (mgd). A notable feature of the process water system is the practice of "cascading," or "counter-current" use of water by which the waste water from one operation becomes the input to another in a series of reuses. Also recycled are the condensed vapors from chemical recovery process units and by-product operations. By these internal measures, the total process water demand is met by withdrawals of only 5.2 mgd. About 1.7 mgd are lost by vaporization, and the volume of the process water effluent approximates 3.5 mgd.

The intensive reuse of process water is already common in kraft mills. Some mills with good reuse practices are already satisfying 80% and more of gross process water requirements with reused water. This water is being reused with no special treatment except for the addition of biocides and other conditioning chemicals.

The hypothetical kraft process system of 1985 carries water reuse still further by taking two additional steps. (1) Vacuum pump seal water is largely recaptured after use and recirculated in a tight system. (2) After the wastewater has received the tertiary treatment required under PL 92-500 to be achieved by 1983, about half of it is substituted for make-up water. The result of these two improvements on an already efficient operation is that the hypothetical unbleached kraft process system will supply nearly 92% of its gross water requirements with reused and recycled water.

There is an additional demand of 16.2 mgd of water for non-contact cooling and condensing in the operations of the digesters, indirect evaporators, lime kiln, and paper machine. In these uses the water absorbs 2.7 billion BTU's of waste heat per day and is elevated an average 20°F in temperature. Although at present most paper mills use once-through cooling systems, our hypothetical plant uses a recirculating system with cooling towers to comply with pollution control requirements.

It is assumed that the kraft mill obtains its water supply from a river adjacent to the mill. Before it can be used, the water must receive treatment, which is done in facilities owned and operated by the mill. Water intended for process use must be treated by settling, coagulation, and filtration. Water for non-contact cooling can be of lower quality, and the only treatment received is settling and addition of

Figure K—2. **Overview Of Unbleached Kraft Linerboard Mill Process Water System**

(1000 TONS PER DAY)

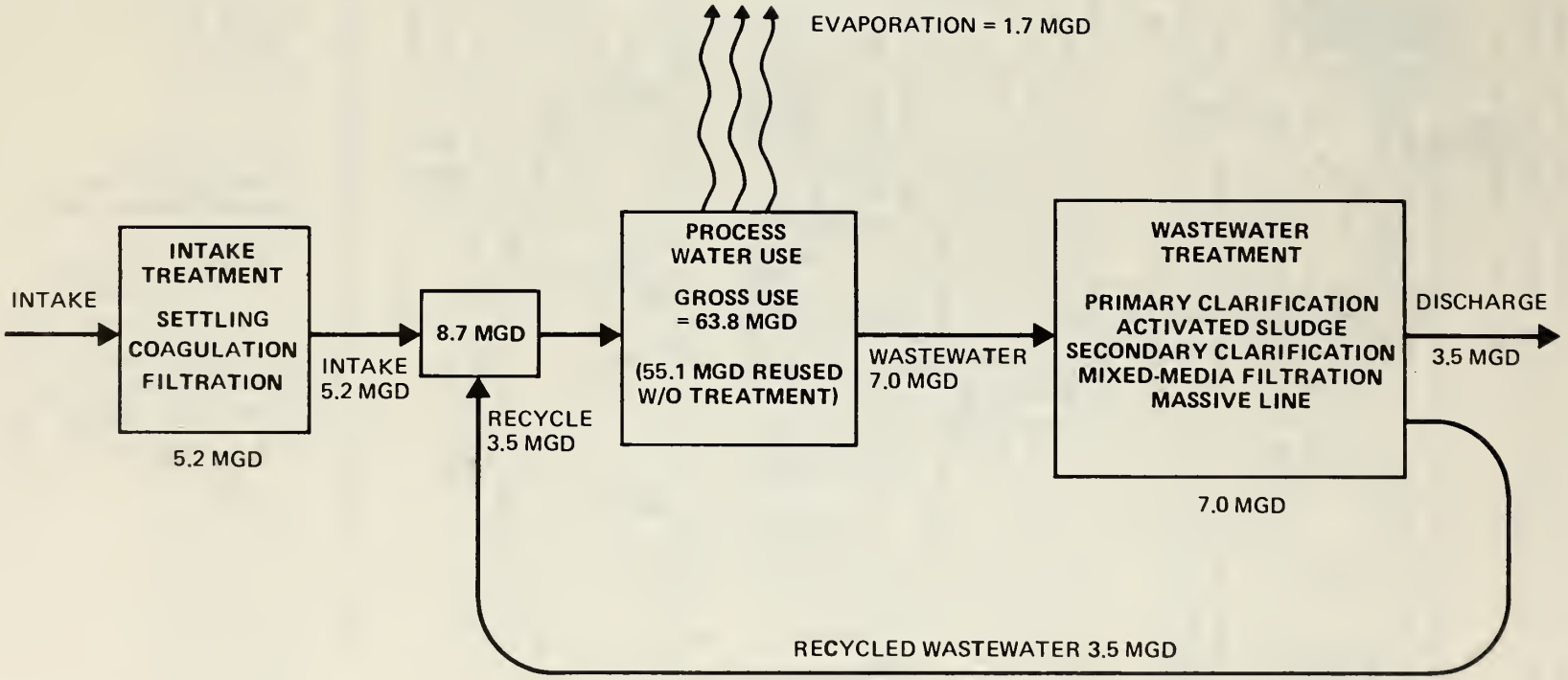

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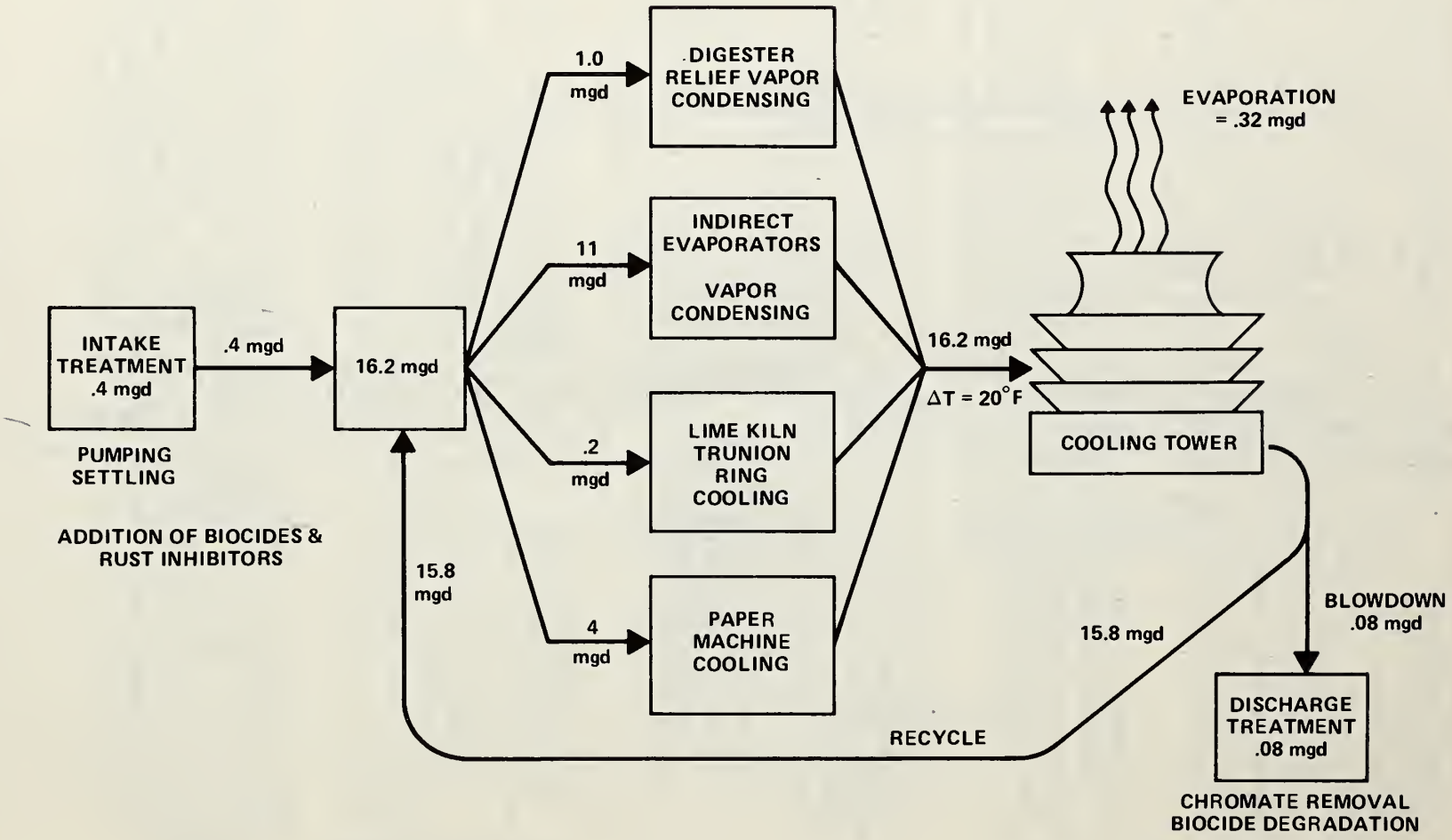
Figure K—2A. **Overview Of The Kraft Paper Mill Non-Contact Cooling Water System**



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biocides and anti-corrosives. It is also assumed that the mill owns and operates waste water treatment facilities for pollution control that are in compliance with the EPA effluent limitation guidelines for 1983.

For the process water effluents the facilities provide primary clarification, activated sludge treatment, secondary clarification, mixed-media filtration, and massive lime coagulation, plus facilities for recalcining spent lime and disposal of sludge. Process effluents treated in this manner are assumed to be suitable for recycling in the mill, provided that the build-up of dissolved solids in the circulating water is controlled by blowdown. As has been stated above it is assumed in this analysis that half of this treated wastewater can be recycled.

For the heated cooling water, it is assumed the EPA guidelines for control of thermal discharges are met by treatment in an induced-draft evaporative cooling tower which transfers the heat to the atmosphere by evaporation of 2 percent of the water flow, whereupon the remaining water is suitable for discharge or for recycling as a coolant. If the cooling water is recycled, it is assumed that the concentration of its dissolved solids may be allowed to increase to 500 percent of the original concentration. This will be controlled by blowdown of 0.5 percent of the water flow. (See Appendix A for more detailed explanation of cooling system evaporation and blowdown.)

If the cooling water is recirculated, corrosion inhibitors and biocides will be added to the circulating water to safeguard the heat exchange equipment and system and to maintain heat transfer efficiencies. The blowdown will then require treatment for removal of the corrosion inhibitors and biocides before it can be discharged. For the price/cost sensitivity analysis, it is assumed that the corrosion inhibitors will be removed by an electrolytic process and that the biocides used are degradable and removed in the process.

Further Water Conservation in the Paper Mill

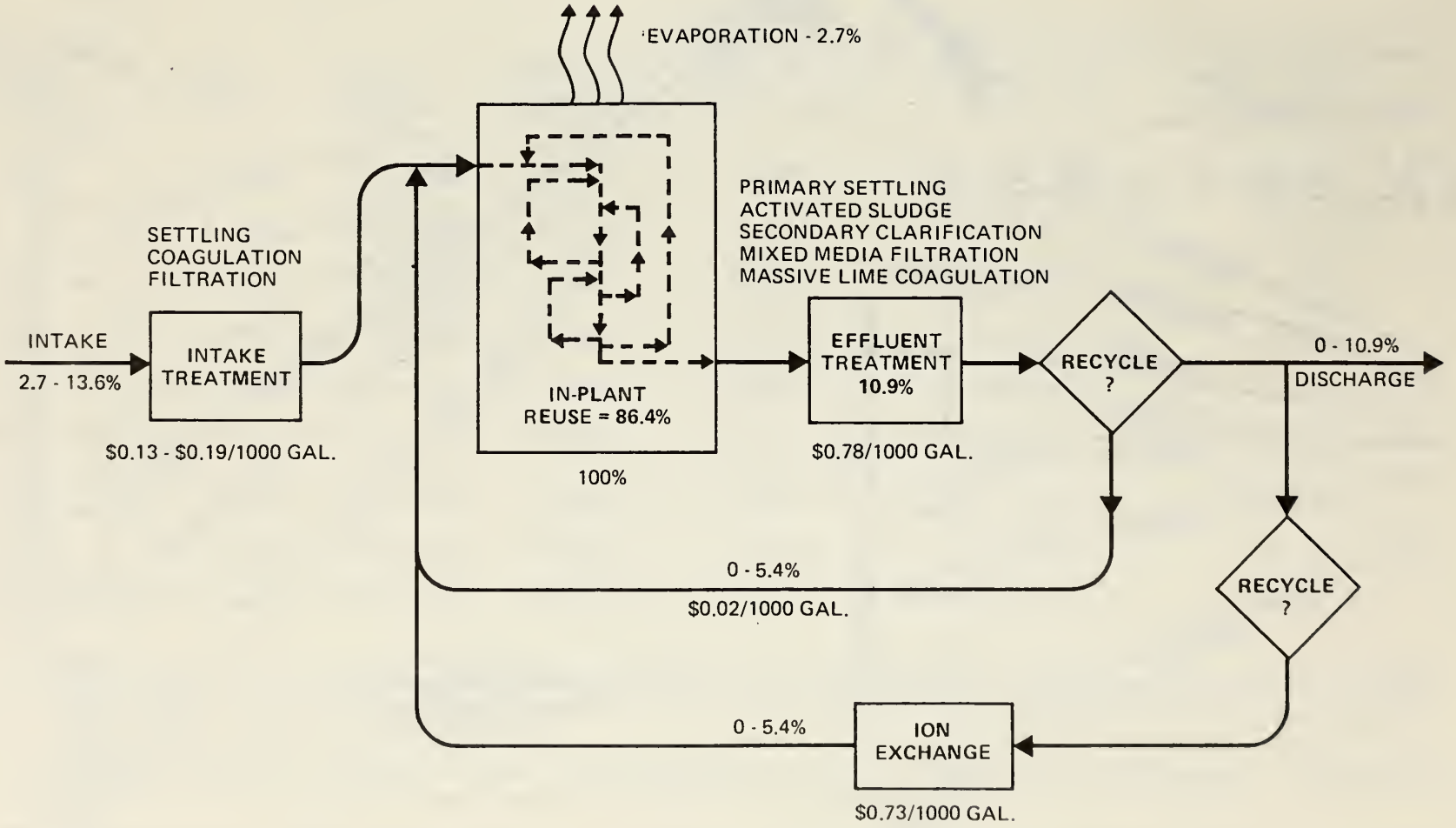
Even though the hypothetical paper mill is already reusing water intensively, if the blowdown from the cooling tower and the process waste treatment plant were to receive a higher level of treatment, there is still some potential for further recycling. This appears to be the most promising

way the kraft mill could reduce its intake to avoid paying the "price" charged for water. A mathematical model of the process water system was developed to determine the least-cost level of recycling associated with various prices of water. A flow chart of this model is shown in Figure K-3. This flow chart shows the maximum volumes that can be recycled at various levels of treatment and the costs of each type of treatment.

Figure K-4 shows the family of curves generated by the model. Even with zero price it is cost-effective for the mill to recycle at a high rate, with a small blowdown discharge to prevent a build-up of dissolved salts from damaging equipment. To achieve a higher level of recycling would require ion-exchange demineralization. This would not ordinarily be economical. It can be seen that a price of $.25/1000 gal. would not provide enough incentive to recycle further. The paper mill would simply pay the price and continue the same water use practices as before. It would not be cost-effective to recycle the blowdown unless the price of water were at least $.75 per thousand gallons. At these high prices, the percentage of recycled water to total gross water use would increase from 91.8% to 97.3%. The plant would then be operating on approximately a zero discharge basis. The only water intake would be to replace water lost by evaporation, incorporation in products and by-products, leaks or other losses. (An analysis of the kraft mill's non-contact cooling system would be very similar to the non-contact cooling system described in the previous section.)

Table K-1 shows what this would mean in terms of manufacturing costs and water conservation. (Table K-2 shows the effects on the process system alone and Table K-3 shows the effects on the non-contact cooling system.) Even with a zero price for water withdrawals, the paper mill incurs $12,618 per day in water-related costs. As higher prices are charged for withdrawals, total water costs increase. However, there is no decrease in water withdrawals unless the price is at least $.75 per thousand gallons. At this price level the model predicts it would minimize costs to demineralize and recycle the blowdown discharges from the process water system. If the water prices were as high as $1.30, it would be economical to recycle the blowdown from the non-contact cooling system. (We are assuming that the blowdowns from the process and cooling systems would have to be treated separately because of their different chemical

Figure K—3. **Unbleached Kraft Pulp & Linerboard Mill - Process Water System - Decision Model**



FLOWS ARE STATED AS PERCENT OF GROSS PROCESS WATER DEMAND - 63.8 MGD

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Figure K—4. **Cost-Effectiveness Of Recycling Process Water In The Hypothetical Kraft Paper Mill**

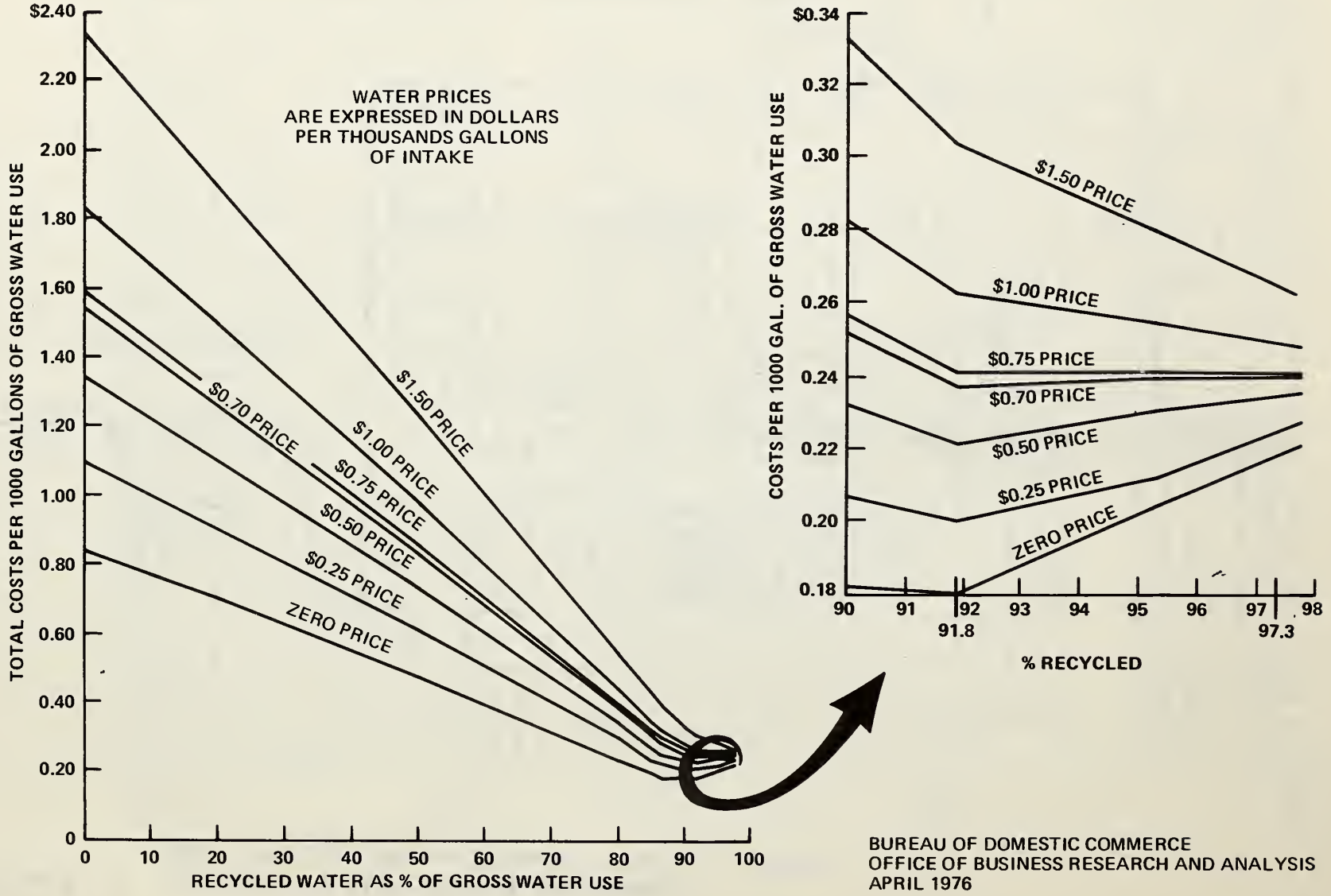

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TABLE K-1. KRAFT MILL COMBINED WATER SYSTEMS*

Plant Operating at Most Cost-Effective Recycling Levels

Water Price (per 1000 gal of Intake)	Water Intake	Water Reused	Water Consumed	Water-related Costs per 1000 gal of Gross Water Use	Water-related Costs per Day	Water Costs as % of Value of production**
0***	28.9 mgd	51.9 mgd	NA	$.085	$6,789	3.5%
0	5.6 mgd	74.4 mgd	2.0 mgd	$.158	$12,618	6.5%
$.10	5.6 mgd	74.4 mgd	2.0 mgd	$.165	$13,177	6.8%
$.50	5.6 mgd	74.4 mgd	2.0 mgd	$.193	$15,445	7.9%
$.70	5.6 mgd	74.4 mgd	2.0 mgd	$.207	$16,563	8.5%
$.75	2.1 mgd	77.9 mgd	2.0 mgd	$.211	$16,851	8.6%
$1.25	2.1 mgd	77.9 mgd	2.0 mgd	$.223	$17,857	9.2%
$1.30	2.0 mgd	77.9 mgd	2.0 mgd	$.224	$17,938	9.2%
$1.50	2.0 mgd	78.0 mgd	2.0 mgd	$.230	$18,425	9.4%

*Gross Water Use = 80.0 mgd. This includes 63.8 mgd for the process system and 16.2 mgd for the non-contact cooling system. It does not include water used for log handling or in the power plant.

**Hypothetical mill produces 1000 tons per day of unbleached kraft linerboard. Value=$195 per ton. Costs and prices based on March 1975 price levels.

***Special Case. Costs and recycling practices indicated in the absence of water pollution control requirements. All other cases assume plant is meeting PL 92-500 standards (best available technology.)

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TABLE K-2.. KRAFT MILL PROCESS WATER SYSTEM

Plant Operating at Most Cost-Effective Recycling Levels

Water Price (per 1000 gal of Intake)	Water Intake	Water Reused	Water Consumed	Water-related Costs per 1000 gal of Gross Water Use	Water-related Costs per day	Water Costs as % of value of product
0*	12.7 mgd	51.1 mgd	1.7 mgd	$.095	$6,060	3.1%
0	5.2 mgd	58.6 mgd	1.7 mgd	$.180	$11,484	5.9%
$.10	5.2 mgd	58.6 mgd	1.7 mgd	$.188	$11,994	6.2%
$.50	5.2 mgd	58.6 mgd	1.7 mgd	$.221	$14,100	7.2%
$.70	5.2 mgd	58.6 mgd	1.7 mgd	$.237	$15,121	7.8%
$.75	1.7 mgd	62.1 mgd	1.7 mgd	$.240	$15,312	7.9%
$1.25	1.7 mgd	62.1 mgd	1.7 mgd	$.254	$16,205	8.3%
$1.30	1.7 mgd	62.1 mgd	1.7 mgd	$.255	$16,269	8.3%
$1.50	1.7 mgd	62.1 mgd	1.7 mgd	$.261	$16,652	8.5%

*Special Case. Assumes no water pollution control requirements. All other cases assume plant is meeting Public Law 92-500 standards (Best Available Technology).

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TABLE K-3. KRAFT MILL NON-CONTACT COOLING SYSTEM

Plant Operating at Most Cost-Effective Recycling Levels

Water Price (per 1000 gal. of intake	Water Intake	Water Recycled	Water Consumed	Water-related Costs per 1000 gal. of Gross Water Use	Water-related costs per day	Water Cost % of Value of prod.**
0*	16.2 mgd	0	NA	$.045	$729	.4%
0	.36 mgd	15.8 mgd	.29 mgd	$.070	$1134	.6%
$.10	.36 mgd	15.8 mgd	.29 mgd	$.073	$1183	.6%
$.50	.36 mgd	15.8 mgd	.29 mgd	$.083	$1345	.7%
$.75	.36 mgd	15.8 mgd	.29 mgd	$.089	$1442	.7%
$1.00	.36 mgd	15.8 mgd	.29 mgd	$.095	$1539	.8%
$1.25	.36 mgd	15.8 mgd	.29 mgd	$.102	$1652	.8%
$1.30	.29 mgd	15.9 mgd	.29 mgd	$.103	$1669	.9%
$1.50	.29 mgd	15.9 mgd	.29 mgd	$.107	$1773	.9%

*Special Case. Costs and recycling practices indicated in the absence of water pollution control requirements. All other cases assume plant is meeting Public Law 92-500 standards. (Best Available Technology)

**Hypothetical will producing 1000 tons per day of unbleached kraft lineboard. Value = $195 per ton.

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compositions. Since the cooling water blowdown stream is much smaller, the cost per thousand gallons is higher.) A price of $1.30 per thousand gallons would increase daily water-related costs from $12,618 per day to $17,938. In the long run these costs would be passed on to consumers in the form of higher prices.

Table K-1 also shows the effects that increased recycling would have on the consumption of water by the kraft mill. There is no reduction in consumption, even though withdrawals have been reduced, because recycling merely uses wastewater to replace intake water. Since discharges are reduced by the same amount as intake, the quantity of water available to users downstream from the paper mill is unchanged. If the effect of water pricing is to reduce water consumption, then a price of $1.30 per thousand gallons would not have the desired effect.

Additional methods of reducing water withdrawals besides recycling have been suggested. The range of additional water conservation measures that could be considered would include:

(1) dry cooling towers

(2) dry fume scrubbing

(3) tighter control of leaks and waste

(4) substitution of other solvents for water

(5) additional vapor recovery condensers

(6) dry forming of paper

These technologies are not currently used in the paper industry, and are not likely to be used in the foreseeable future. Generally they would involve higher costs, and some of them would also increase energy consumption, cause air and water pollution, create occupational safety hazards, and/or consume resources more scarce than water. In some cases a reduction in process water use would be offset by increased water needs in the power plant system. A discussion of each alternative gives an indication of its benefits and drawbacks.

"Dry" Cooling Towers. Dry cooling towers cool the heated wastewater in the same way as an automobile radiator, on a much larger scale. If the standard evaporative cooling tower in the noncontact cooling system were replaced with a dry tower, then 290,000 gallons per day in evaporative

losses could be avoided. The major drawback to dry cooling towers is the high cost. It has been estimated that a price of $4.00 per thousand gallons would be required to make dry cooling towers economical. (This subject is discussed in greater detail in the non-contact cooling section.)

"Dry" Fume Scrubbing. The process water system uses about 570,000 gallons per day for fume scrubbing, of which 50,000 is consumed. It has been suggested that techniques such as electrostatic precipitation could be used instead of wet fume scrubbing systems. But it is unlikely that dry systems will be used in the place of wet systems, because dry systems by themselves are not capable of meeting strict air pollution control requirements regarding noxious gases.

Tighter Control. There is some potential for reducing waste of water due to leaks and carelessness. However, the amount of water is relatively small, perhaps 5% of the total of water consumed. Many of the leaks may not be worth fixing. For example, a small leak in a pipe under the factory would probably be left alone, since the plant might have to be closed down and the floor would have to be torn up in order to locate and repair the leak.

Substitution of Other Solvents for Water. No acceptable substitute for water in kraft paper making process uses is currently known. Most other solvents release vapors that could cause serious environmental and occupational safety hazards. Leaks and spills of solvents other than water could result in pollution of streams or groundwater. An additional drawback to substitute solvents is their much higher cost relative to water.

Water Vapor Recovery Condensers. In this model kraft mill, the indirect evaporators and the turpentine decanters are equipped with condensers which recapture over 1.5 mgd of water vapor. It is logical to look for other places in the mill where condensers could effect further water savings. However, a feasibility check reveals good reasons why condensers are not more widespread. A major shortcoming is that condensers require huge volumes of cooling water. This cooling water must then be run through cooling towers, with attendant evaporative losses. Another drawback to condensers is the large power requirement. The generation of electric power consumes water as well as energy. It turns out that the indirect evaporators and the turpentine decanters are special cases which make water recovery practical. Aside from the blow steam of the continuous digesters (the model plant uses the more common batch

digesters), vapor recovery condensers are probably not practical at other points of evaporative loss.

Dry Forming of Paper. Since half the water used in making unbleached paper is required for forming the fibers into paper, the feasibility of utilizing a dry forming process as a water saving alternative has been examined. At present there is no known method of converting fibers into most grades of paper without the use of water.

Although a Japanese manufacturer has developed a dry forming machine for converting corrugating mill waste into a product called Flemat, that product is not paper and cannot be substituted for paper in its most important uses. Several other foreign manufacturers are experimenting with dry forming of other products from mill waste, but these are still in the prototype stage.

It is highly unlikely that kraft paper can be replaced by dry-formed paper in the foreseeable future.

Conclusions

This simulated kraft paper mill is already a highly efficient user of water, even with no "price" charged for water withdrawals. Water-related costs total thousands of dollars per day, and must be minimized like other costs. To minimize these water costs the paper mill has employed all of the easy methods of water conservation as well as many of the non-so easy ones. This study has analyzed other water conserving techniques the kraft mill could consider, and has found none that are technologically or economically feasible alternatives.

WATER USE IN STEELMAKING

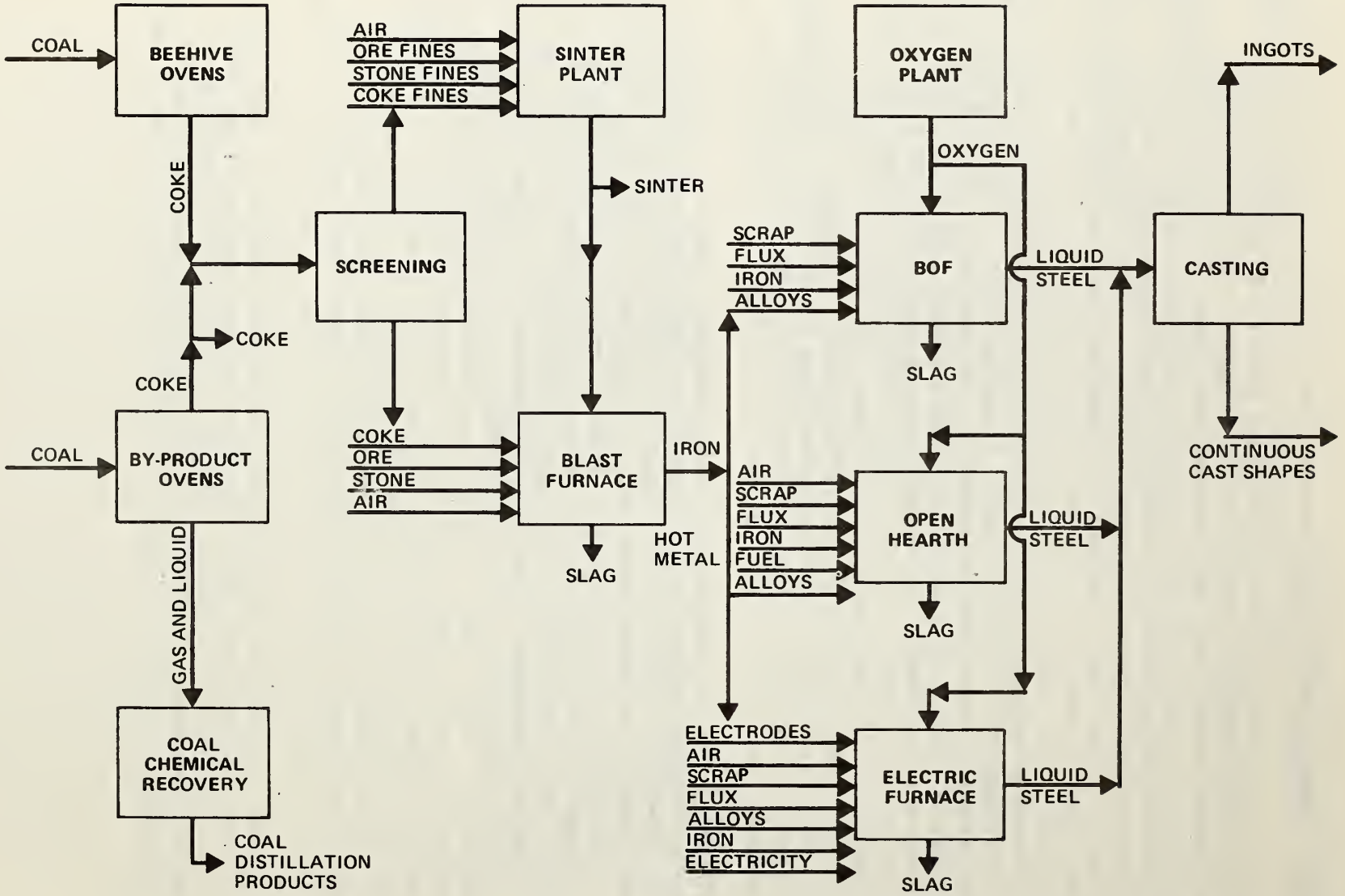
The U.S. steel industry produces about 140 million tons of steel annually, and is a cornerstone of the national economy. Over 500,000 persons are directly employed in producing steel and basic steel products. Major industries directly dependent upon steel include machinery, motor vehicles, shipbuilding, construction, aircraft, and many others. The steel industry is the largest manufacturing consumer of energy, and the third largest user of water.

The steel industry includes about 925 manufacturing establishments. However, only about 60 mills carry on the basic steelmaking activities -- the rest make alloys and products from steel ingots. These large integrated mills perform a multiplicity of operations that include the conversion of coal to coke, the conversion of iron ore to iron, from which steel is produced, and the forming of finished steel products from the slabs, billets, and ingots of the steelmaking operations. (see figure S-1) All these steps use water in large volumes for process operations, cooling, power generation, and air pollution control.

Figure S-1 also indicates that there are several alternative technologies for many of the steelmaking operations. For example, steel can be made from iron in basic oxygen furnaces, open hearth furnaces, and electric furnaces; and it is common to find two or more types of steelmaking furnaces in a large mill. Because of the immense capital costs, the replacement of older technology by the new is a gradual process. The trend appears to be toward basic oxygen furnaces, continuous casting, and larger blast furnaces. Very few, if any, open hearth furnaces should be operative in 1985. Electric furnaces produce both high-quality steel and standard grades, but expansion in electric furnace capacity is limited somewhat by the availability of scrap steel. It is likely that basic oxygen furnaces, which currently produce over 60% of the steel made in the United States, will account for an even larger share in 1985.

For the Price/Cost Sensitivity Analysis the focus has been on three major unit operations; the conversion of molten iron to steel in a basic oxygen furnace, the degassing of the molten steel, and the casting into billets by the continuous casting process. These operations are only part

Figure S—1. **Major Operations In Steelmaking**



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of the activities of a steel mill but a study of an entire complex would not have been manageable for the purposes of this project. The analyses are based on simulated steelmaking facilities producing 9000 tons of steel per day -- a medium sized operation.

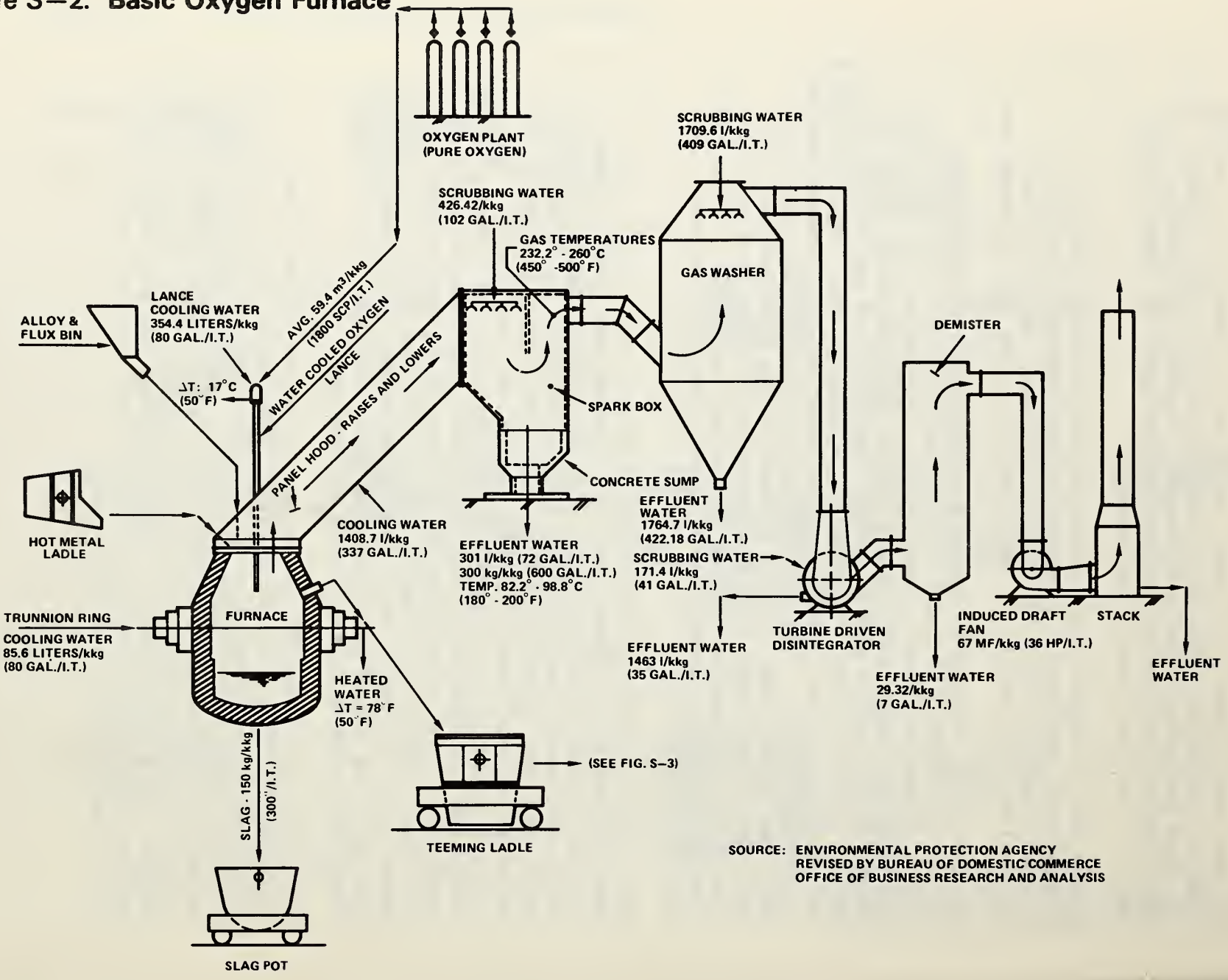
There are 11 major uses of water in the steel making operations analyzed. Seven of these uses are for non-contact cooling, one is contact cooling, two are fume scrubbing, and one is in the form of steam for process use.

In the basic oxygen furnace, in which iron is converted to steel, there are four major uses of water (See figure S-2). Three of these uses involve non-contact cooling of the oxygen lance, the trunion ring, and the panel hood. Evaporative losses and blowdown requirements are relatively small, and untreated wastewater is sent to the cooling towers and recycled. The fourth use of water is for fume scrubbing of exhaust gases. This requirement accounts for more than half the water used in the furnace. The wastewater from this use is hot and high in suspended solids, and must be clarified and cooled before it can be recycled. Evaporative losses are high, about 12% of gross use, and blowdown is another 9%.

The vacuum degassing operation includes four water uses. (see figure S-3) There are two non-contact cooling uses, for the transformer bus tube and the vacuum seals. The volume of water required for these two uses is relatively small and the thermal loadings are low, and this water can be recycled with small losses in the cooling tower. The largest water use is for fume scrubbing in the barometric condenser. Wastewater from this use must receive chemical coagulation and clarification before it can be cooled and recycled. The fourth water use is process steam for the steam ejector, which requires very little water input. Some of this steam goes out the stack and the rest becomes mixed with the fume scrubbing wastewater.

The continuous casting operation converts molten steel into solid semi-finished shapes. The three water uses in this system are shown in figure S-4. Two of the uses, mould cooling and cutting machine cooling, employ ordinary non-contact cooling systems. The third water use is for spray cooling of the molten steel as it is cast into semi-finished shapes. The consumptive losses in this use are high (11%), and the wastewater must be settled and filtered before it can be sent to the cooling tower.

Figure S—2. Basic Oxygen Furnace



SOURCE: ENVIRONMENTAL PROTECTION AGENCY
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Figure S—3. **Vacuum Degassing**

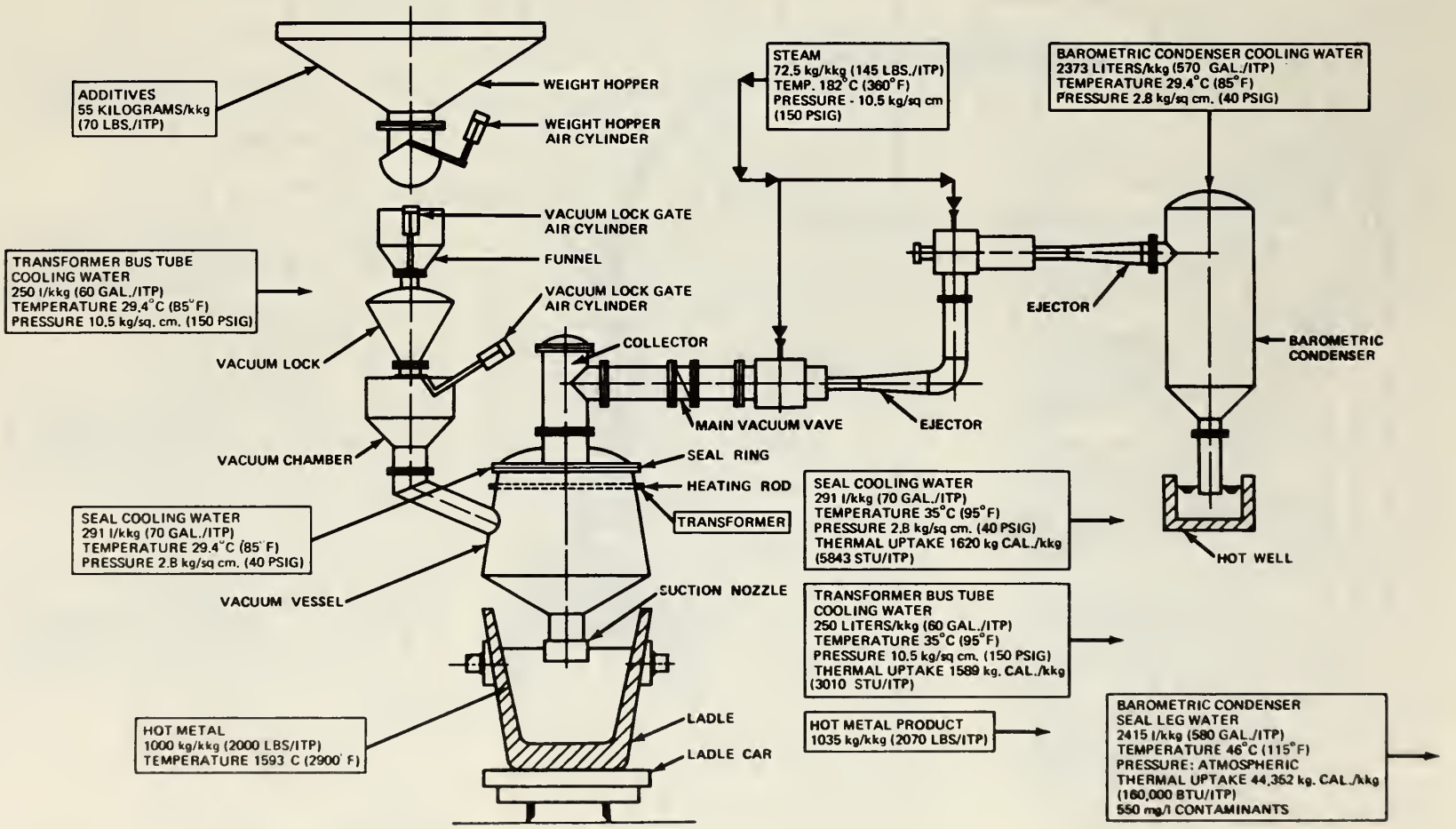

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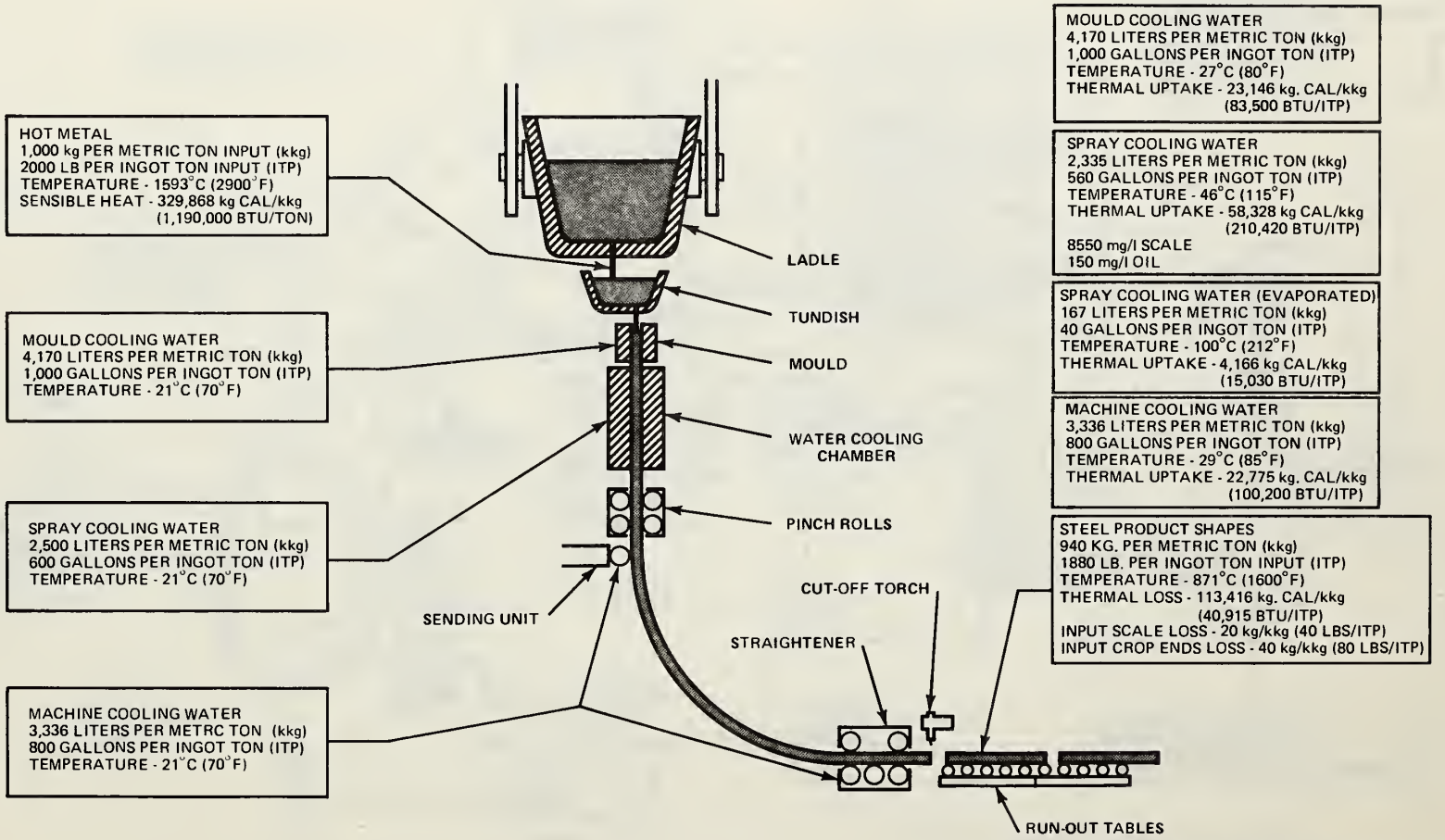
Figure S—4. **Continuous Casting**


HOT METAL
1,000 kg PER METRIC TON INPUT (kkg)
2000 LB PER INGOT TON INPUT (ITP)
TEMPERATURE - 1593°C (2900°F)
SENSIBLE HEAT - 329,868 kg CAL/kkg
(1,190,000 BTU/TON)
MOULD COOLING WATER
4,170 LITERS PER METRIC TON (kkg)
1,000 GALLONS PER INGOT TON (ITP)
TEMPERATURE - 21°C (70°F)
SPRAY COOLING WATER
2,500 LITERS PER METRIC TON (kkg)
600 GALLONS PER INGOT TON (ITP)
TEMPERATURE - 21°C (70°F)
MACHINE COOLING WATER
3,336 LITERS PER METRC TON (kkg)
800 GALLONS PER INGOT TON (ITP)
TEMPERATURE - 21°C (70°F)
LADLE
TUNDISH
MOULD
WATER COOLING CHAMBER
PINCH ROLLS
SENDING UNIT
CUT-OFF TORCH
STRAIGHTENER
RUN-OUT TABLES
MOULD COOLING WATER
4,170 LITERS PER METRIC TON (kkg)
1,000 GALLONS PER INGOT TON (ITP)
TEMPERATURE - 27°C (80°F)
THERMAL UPTAKE - 23,146 kg. CAL/kkg
(83,500 BTU/ITP)
SPRAY COOLING WATER
2,335 LITERS PER METRIC TON (kkg)
560 GALLONS PER INGOT TON (ITP)
TEMPERATURE - 46°C (115°F)
THERMAL UPTAKE - 58,328 kg CAL/kkg
(210,420 BTU/ITP)
8550 mg/l SCALE
150 mg/l OIL
SPRAY COOLING WATER (EVAPORATED)
167 LITERS PER METRIC TON (kkg)
40 GALLONS PER INGOT TON (ITP)
TEMPERATURE - 100°C (212°F)
THERMAL UPTAKE - 4,166 kg CAL/kkg
(15,030 BTU/ITP)
MACHINE COOLING WATER
3,336 LITERS PER METRIC TON (kkg)
800 GALLONS PER INGOT TON (ITP)
TEMPERATURE - 29°C (85°F)
THERMAL UPTAKE - 22,775 kg. CAL/kkg
(100,200 BTU/ITP)
STEEL PRODUCT SHAPES
940 KG. PER METRIC TON (kkg)
1880 LB. PER INGOT TON INPUT (ITP)
TEMPERATURE - 871°C (1600°F)
THERMAL LOSS - 113,416 kg. CAL/kkg
(40,915 BTU/ITP)
INPUT SCALE LOSS - 20 kg/kkg (40 LBS/ITP)
INPUT CROP ENDS LOSS - 40 kg/kkg (80 LBS/ITP)

SOURCE: ENVIRONMENTAL PROTECTION AGENCY
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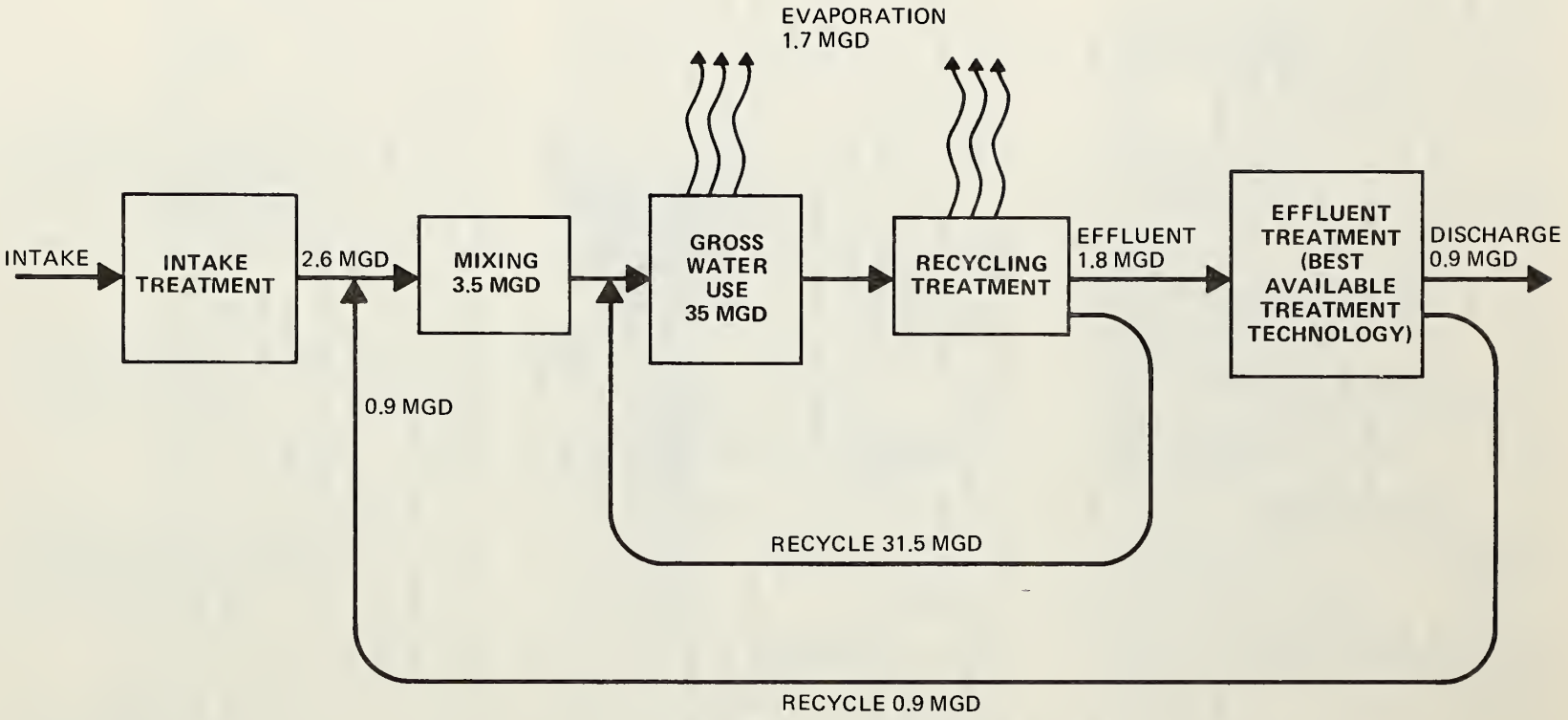
Very few integrated steel mills obtain their water supplies from public water systems, except to provide water for personal use of employees. Most steel mills withdraw water directly from streams, lakes, estuaries, or wells. For our hypothetical plant it is assumed that water is withdrawn from a river and treated in facilities owned and operated by the mill. Water used for non-contact cooling has relatively low quality requirements, and the only treatment required prior to use is settling and the addition of biocides and corrosion inhibitors. Water intended for spray cooling use has a higher water quality requirement, and must receive settling, coagulation, and filtration. The strictest quality requirement is the steam for the steam ejector. Before feedwater is sent to the boilers, it receives settling, coagulation, and filtration, and then is demineralized.

The wastewater flows from different uses are segregated to make them easier to treat and recycle. There is a recycling water system for each water use, with make-up water required only to replace evaporative losses and the "blowdown" discharges necessary to prevent the concentration of dissolved solids in the system. The blowdown discharges are treated to high quality levels required by 1983 water discharge standards (best available treatment technology). These treated blowdown streams could legally be discharged; however this water will be better than the make-up water in many respects, and to a large extent it can be recycled to reduce make-up requirements. The limiting factor in recycling this highly-treated effluent is the necessity of preventing the dissolved solids from building up to concentrations which could cause damage to heat-exchangers, cooling towers, and other equipment.

The water balance of the hypothetical steel mill is shown in figure S-5. Of the 35 million gallons per day (mgd) used in the operations studied, only 2.6 mgd need to be replaced with make-up water. This intake water is needed to replace 1.7 mgd. consumed during use plus 0.9 mgd of blowdown which is discharged to prevent a build-up of dissolved salts in the system. More than 92% of the mill's water needs are met with reused water (32.4 mgd). This high degree of water reuse is a result of the Water Pollution Control Act Amendments of 1972. If it were not for these water pollution control requirements, water reuse would be much less intensive.

Figure S—5. **Water Balance Of The Steel-Making Operations**



NOTE: THIS REPRESENTS MOST COST-EFFECTIVE WATER USE PRACTICES IN THE ABSENCE OF WATER PRICES.

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Although this hypothetical system is already an efficient user of water, there is some potential for further reductions in intake. The most likely possibility would be to recycle the water discharged. The volume of these discharges is 0.9 mgd, or 2.6% of the gross water used. Water pricing would, of course, provide some incentive to recycle this water. However, determining the effectiveness of this incentive is a difficult task, for which a mathematical model was developed to provide more rigorous analysis.

The model attempts to simulate the decision-making process of the manager of the steel mill in predicting the response to water prices. This approach views the price of water as one of several costs which must be considered in choosing the optimum recycling strategy. This is a complicated decision, involving cost trade-offs and physical/chemical constraints. A flowchart used to develop the model is shown in Figure S-6. The output of the model is a cost curve for each water price under consideration. These cost curves demonstrate the total water-related costs associated with various levels of recycling. The lowest point on each cost curve indicates the degree of recycling which the plant should employ.

Figure S-7 shows the cost curves which the model predicts would result from pricing the raw water intake of the steel mill. Water prices in the range of $.10 to $.25 per 1000 gallons would have no significant impact in reducing the steel mill's withdrawals. It would be more logical to simply pay the "price" for make-up water and continue to operate the water system exactly as before. Not unless water prices were raised to at least $.95 per 1000 gallons would it be attractive to reduce intake from 2.6 mgd. to 1.7 mgd. This would be accomplished by demineralizing the final blowdown discharge and recycling it to the head of plant. The water system would then be operating with essentially zero discharge. Operating costs would be increased by $2450 per day for these steps in the steelmill's operation. (see Table S-1)

If water prices were raised higher than the $.95 required to induce recycling of blowdown, the only result would be an increase in the cost of making steel. This is because any further reductions in water intake would come at extremely high costs. For example, the evaporative cooling tower in the non-contact cooling system could theoretically be replaced with a "dry" cooling tower, but this would not

Figure S—6. Decision Model For Steelmaking Water System

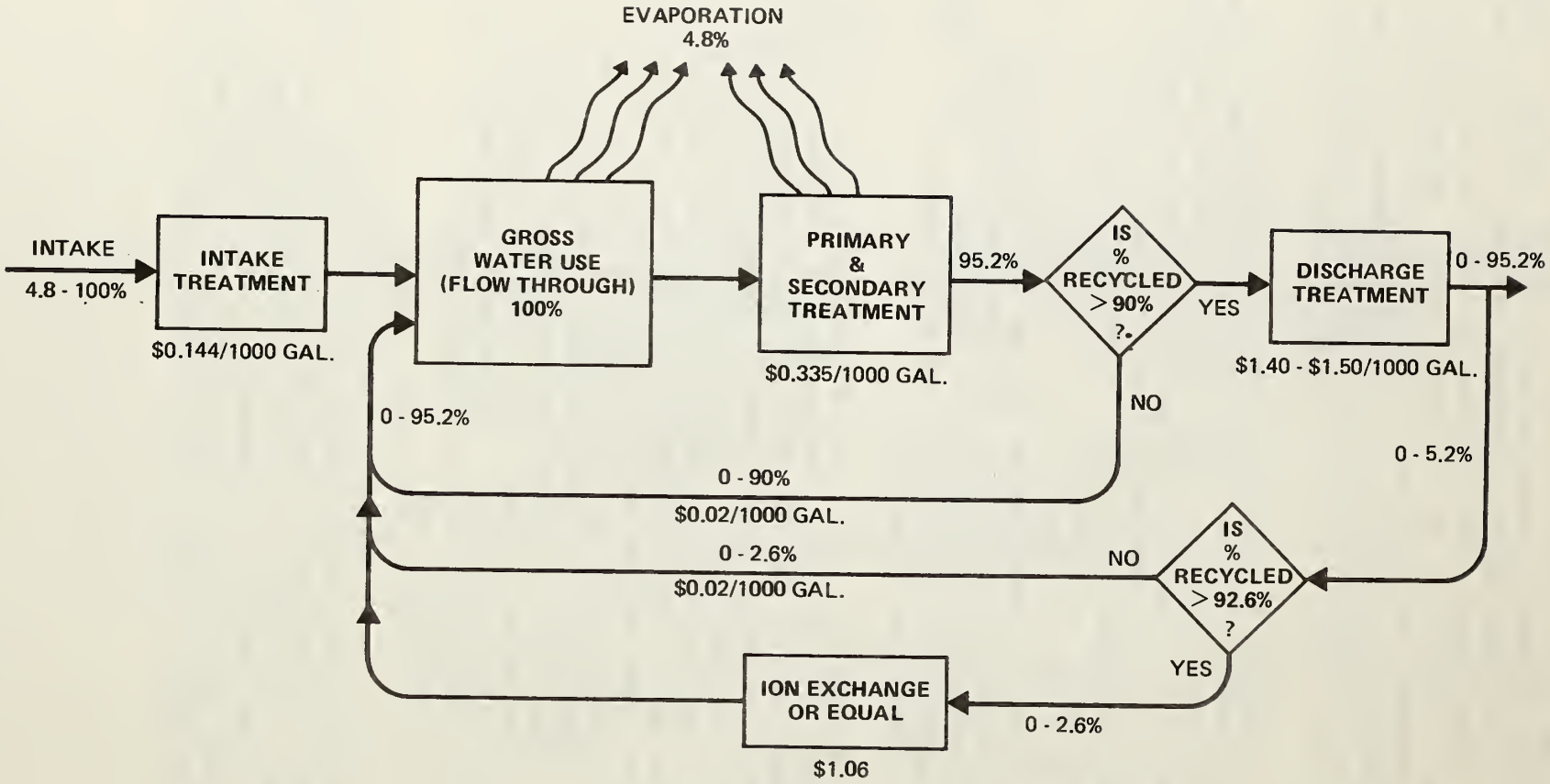

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Figure S—7. **Cost-Effectiveness Of Recycling In Simulated Steelmaking Operations**

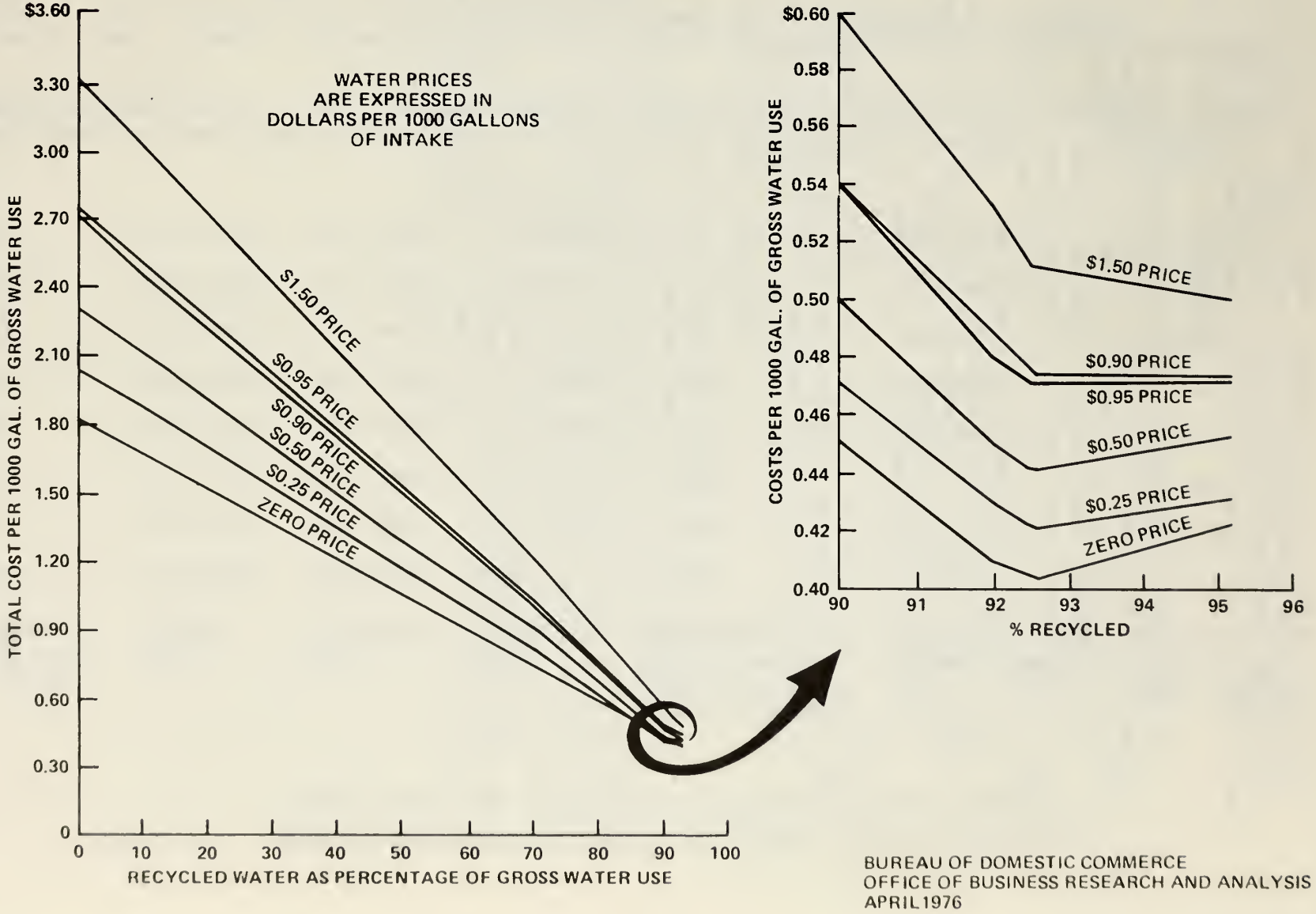

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TABLE S-1. EFFECTS OF WATER PRICING ON THE STEEL MAKING OPERATIONS*

Plant Operating at Most Cost-Effective Recycling Levels

Water Price (per 1000 gal of intake	Water Intake	Water Recycled	Water Consumed	Water-related Costs per 1000 gal of Gross Water Use	Water-related costs per day	Water Costs per ton of steel*
0**	31.3 mgd	3.69 mgd	NA	$.117	$4,095	$.44
0	2.62 mgd	32.4 mgd	1.68 mgd	$.405	$14,175	$1.58
$.10	2.62 mgd	32.4 mgd	1.68 mgd	$.412	$14,420	$1.60
$.25	2.62 mgd	32.4 mgd	1.68 mgd	$.423	$14,805	$1.64
$.50	2.62 mgd	32.4 mgd	1.68 mgd	$.442	$15,470	$1.72
$.90	2.62 mgd	32.4 mgd	1.68 mgd	$.472	$16,520	$1.84
$.95	1.68 mgd	33.3 mgd	1.68 mgd	$.475	$16,625	$1.85
$1.00	1.68 mgd	33.3 mgd	1.68 mgd	$.477	$16,695	$1.86

*The operations analyzed in this study are only part of the total activities of an integrated steel mill. Cost estimates reflect only part of the costs which would be caused by water pricing.

**Special Case. Costs and recycling practices indicated in the absence of water pollution control requirements. All other cases assume plant is meeting Public Law 92-500 effluent standards (Best Available Technology).

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be practical unless water prices were at least $4.00 per 1000 gallons. Aside from the prohibitively high cost of such a system, there are possible environmental hazards and operational problems that would make dry cooling towers undesirable for a steel mill.

It has been suggested that water pricing could lead to the replacement of water-using technologies with alternative technologies that accomplish the same task wihout the use of water. A review of such technologies likely to be available in the foreseeable future indicates there are no realistic possibilities for steel mills to reduce water use in this way. For example, substitution of air cooling for water cooling is not practical because of the vast volumes of air that would be needed. (About 3300 cubic feet of air are required to perform the cooling done by one cubic feet of water.) A similar example is fume-scrubbing use of water. The substitution of "dry" fume and particulate collectors such as electrostatic precipitators, for the "wet" fume scrubbing systems are also not practical alternatives, because of their high costs and energy requirements, and their inability to meet Clean Air Act amission standards.

The three operations analyzed in this study account for only a fraction of the water use in an integrated steel mill, but they are fairly typical. Because of cost minimization pressures and water pollution control requirements, this hypothetical steel mill is already a highly efficient user of water. Since realistic alternatives for reducing water intake will be few, and the ratio of value added to water intake will be high, the steel industry would have a strongly inelastic demand for water intake. Water pricing would not be a practical tool for inducing water conservation in this case.

APPENDIX A

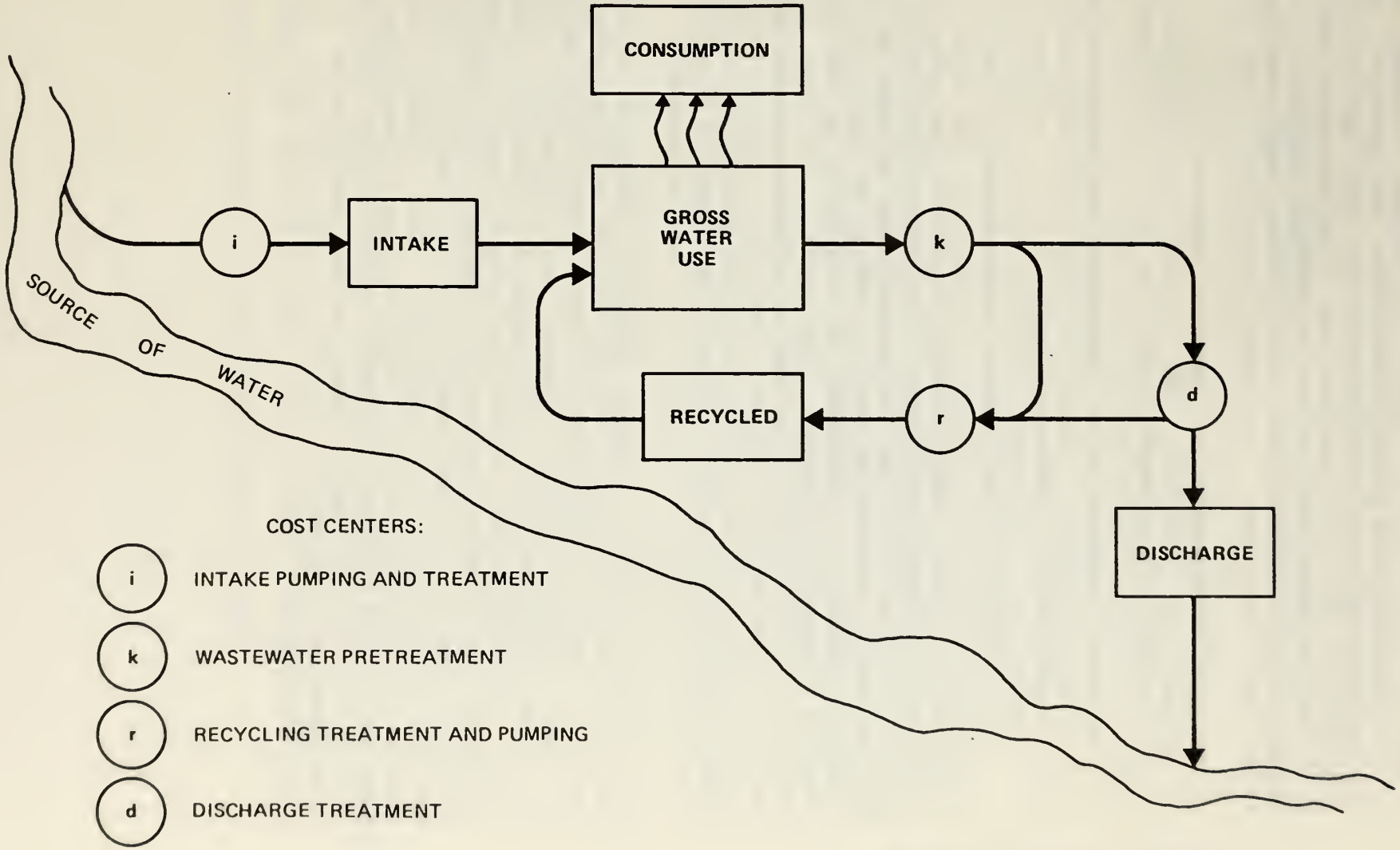
METHODOLOGY AND MATHEMATICAL SIMULATIONS

Determining the sensitivity of industrial water withdrawals to water prices is a complex process, especially if the output must be of high enough quality to use for public policy making. It is not adequate to simply calculate price elasticity coefficients from historical data, because 90% of the water used by industry is obtained with no charges assessed directly from rivers, lakes, estuaries, wells, and other sources. Another reason why analyses of historical data are inadequate is that future water use practices and costs will be radically different from today.

The only satisfactory method of resolving this issue is to study the impact of water pricing on the operating costs of the manufacturing processes, and to determine what course the plant manager would take to minimize costs. The price of water is only one element of the costs incurred in using water, and water is only one of many scarce resources used in manufacturing. For this reason the price/cost sensitivity analysis includes a study of the price and cost factors, the physical and chemical constraints, and the available water-conserving alternatives which the plant manager must consider in the cost minimizing decision. To the extent possible, these factors have been organized into a computerized model which simulated the decision-making process.

In this study the focus is on the 90% of water intake which is self-supplied by the manufacturer. These plants do not, of course, pay any "price" for the water they withdraw. This water is treated by the company to the quality levels required, is sent to where it is needed, and wastewater is treated to the required quality levels. (Although in some cases no wastewater treatment is currently required, strict pollution control guidelines will soon be in effect nationwide.) Very often wastewater is reused to reduce the volume of water intake requirements. Figure 1 is a conceptual diagram of industrial water use. Crucial to the understanding of this analysis is the concept of gross water use, which is the amount of water which would have been withdrawn if no water were reused.

Figure 1. **Water Use Relationships And Cost Centers For Self-Supplied Industrial Water Users.**



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Substantial costs are incurred in the use of water, even in the absence of a price charged for withdrawals. In this price/cost sensitivity analysis, the price of water is only one of many costs that the plant manager must consider in attempting to minimize total capital, operating, and maintenance costs. Other cost considerations would include:

....Intake pumping and related costs

....Intake treatment costs

....Recirculated water treatment and pumping costs

....Discharge treatment costs

....Costs of alternatives to water use

In addition to cost factors which must be considered by the plant engineer are physical and chemical factors which strongly influence the sensitivity to water prices. For example, evaporative cooling towers perform the cooling operation by evaporating a fraction of the water flowing through the system. The fraction of water evaporated is determined by the amount of heat carried in the water and the ambient weather conditions. Water pricing cannot reduce intake beyond the level needed to replace these evaporative losses, unless the plant is forced to discontinue the use of evaporative cooling towers.

A difficulty which arises in making an analysis of this kind is the tremendous diversity of the manufacturing sector. The 300,000 plants in the manufacturing sector vary enormously in size, industry, age, location, source of water, manufacturing technologies, and costs of production. This diversity causes the economic and engineering determinants of price sensitivity to vary widely from plant to plant. In this analysis four specific types of manufacturing plants are simulated. These plants are new plants which are of typical size and use technologies expected to be typical in 1985. It is assumed that these plants are in the design stage, so the analysis is unencumbered by problems of retrofitting and "sunk cost" considerations.

Four separate mathematical models were developed for this study, one for each simulated type of manufacturing establishment. These models use the same basic approach, but the costs, physical constraints, and alternatives are different. This discussion of the model will first explain the basic approach and then will provide a worked example for illustrative purposes.

The basic approach of the model is to estimate separately each water-related cost and then calculate the average weighted total costs per thousand gallons of gross water used. The total water cost per thousand gallons of gross water use will vary according to the water price being considered and the recycling rates at which the plant could operate. Since the plant could reduce payments for water intake by more intensive recycling, the computer calculates the total water costs per 1000 gallons of gross water use that would result from higher recycling rates. For any water price under consideration the model generates a cost curve of total water related costs that would be incurred at alternative levels of recycling, and identifies the least-cost recycling rate the plant manager should employ in response to that price of water intake.

The system of equations, stated in general form, would be:

(1) $I = 1000 - R$

(2) $D = I - C$

(3) $i = K_1 + [(R \div 1000)^z \times K_2]$

(4) $d = K_3 + [[R \div (1000-C)] \times K_4]$

(5) $r = K_5$ if $R<Q$; but if $R>Q$, then $r=K_5+K_6$

(6) $TWC=(Ip)+(Ii)+(1000\ K_7) + (Rr) + (Dd)$

WHERE

TWC=Total Water-related Costs per 1000 gallons of gross use

I=Gallons of Intake per 1000 gallons of gross use

p=Price of Water per 1000 gallons of intake

i=Costs of pumping and treating intake per 1000 gallons of intake

R-Gallons of Water Recycled per 1000 gallons of gross use

C-Gallons of Water Consumed per 1000 gallons of gross use

D=Gallons of Water Discharged per 1000 gallons of gross use

r=Costs of Recycling treatment per 1000 gallons recycled

d=Costs of Discharge treatment per 1000 gallons discharged

z=exponent which allows for geometrically lower costs per 1000 gallons in larger treatment plants.

k_1, k_2=cost factors for calculating costs per 1000 gallons of treating intake water.

k_3, k_4=cost factors for calculating costs per thousand gallons of treating water for discharge

k_5, k_6=cost factors for calculating costs per 1000 gallons of water recycled

k_7=water related costs not included in other cost centers, per 1000 gallons of gross water used. These costs are not affected by changes in recycling rates.

Q=decision point, expressed in gallons of water recycled per 1000 gallons of gross water used. Further recycling beyond this point necessitates additional treatment costs.

Close inspection of the model reveals that the first five equations are preparatory, leading up to the sixth equation, which calculates a weighted average of the total water-related costs (TWC) per 1000 gallons of gross water used. The independant variables are p (water price) and R (recycled water). The other variable, I, D, i, d, and r, are derived by the model in the first five equations. In econometric parlance, p and R are the exogenous variables and I, D, i, d, and r are endogenous variables. The constants (K_1 through K_7) are based on studies of the costs of various water treatment technologies. The decision points (Q) are based on studies of water needs and water reuse possibilities in manufacturing plants.

The object of the price/cost sensitivity analysis is to determine the reduction in intake which would result from water pricing. The model was developed specifically to perform this task. For any given p and R the model will calculate TWC. Thus, to determine the impact of any particular price on water conservation, the procedure is to hold p constant and run the model with alternative values for R. A series of values for TWC will be generated, and the least-cost recycling rate will be at that value of R for which the lowest TWC is observed.

In the process of projecting the least-cost response to water prices, the model provides cost estimates for these responses. These cost estimates can be used to determine the costs per unit of manufactured product that would result from water pricing. This will be shown more clearly in the worked examples that follow.

A drawback to the model as it has been presented so far is that recycling is the only response to water pricing that is analyzed by the model. It can be argued that there are other possibilities for water conservation, such as replacement of water-intensive processes with "dry" alternatives. As a practical matter, however, in the key manufacturing uses of water which we analysed this was not a major limitation. These dry technologies usually would involve unreasonably high costs -- in no case would a price less than $1.50/1000 gal. ($500/acre foot) make these alternatives economical. Another drawback to alternative technologies is that they usually cause new problems. For example, substitution of other solvents for water could be hazardous to employees and to the surrounding environment. In each of the water uses covered in this study, an analysis of possibilities other than recycling has been presented. In none of these cases was an attractive alternative found.

Worked Example of the Model-Non-Contact Cooling System

The workings of the non-contact cooling system is described in detail in another section of this report. A flowchart of the model is given in figure 2. The equations of the model are as follows:

$I = (1000-R)$ gallons

$D = (I-20)$ gallons

$i = 4.5 + (((R \div 1000)^{2.6}) \times 10.5)$ cents/1000 gallons

$d = 133 + ((R \div 980) \times 12)$ cents/1000 gallons

r: if $R < 975$, $r = 2$ cents/1000 gal.

otherwise, $r = \frac{(2 \times 975) + ((1.03 \times (R-975))) \times 277}{R}$ cents/1000 gal.

$TWC = (Ip) + (Ii) + (1000 \times 4.0) + (Rr) + Dd)$

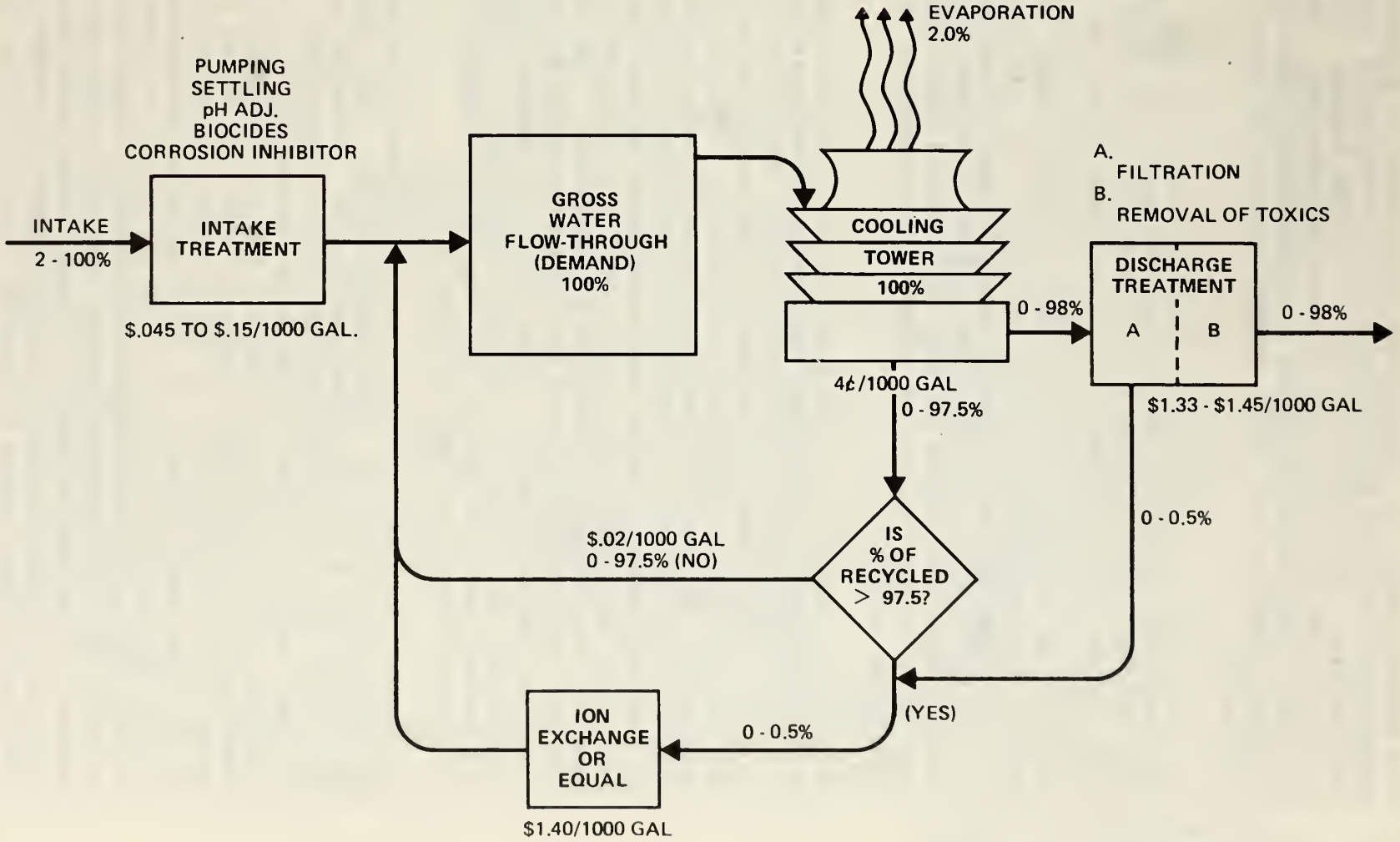
These equations follow the general model exactly. Specific values have been substituted where they are needed.

The first equation calculates the volume of raw water intake per 1000 gallons of gross water use. This equation is derived from the definition of gross water use, which is the amount of water which would have been withdrawn if no water had been reused. Since R is one of the exogenous variables of the model, the value of I is readily obtained.

The second equation calculates the volume of water discharged from the plant, per 1000 gallons of gross water used. All water withdrawn by the manufacturer is eventually consumed or discharged. Since the consumption rate (C) in this model is 20 gallons per 1000 gallons of gross use, and the Intake (I) was obtained from the first equation, the estimate for Discharges (D) follows.

The third equation calculates the cost of water intake per 1000 gallons of intake. (Note that this does not include the price of water, which is handled separately.) The cost of intake water varies from $0.045 to $0.15 per 1000 gallons, according to the volume of water treated. If there were relatively little recycling, the volume of intake would be greater and the cost of treatment per 1000 gallons would be less. Conversely, with intensive recycling there would be higher costs per gallon because of the smaller treatment facility.

Figure 2. **Decision Model For Non-Contact Cooling Water System — 10,000 gpm**



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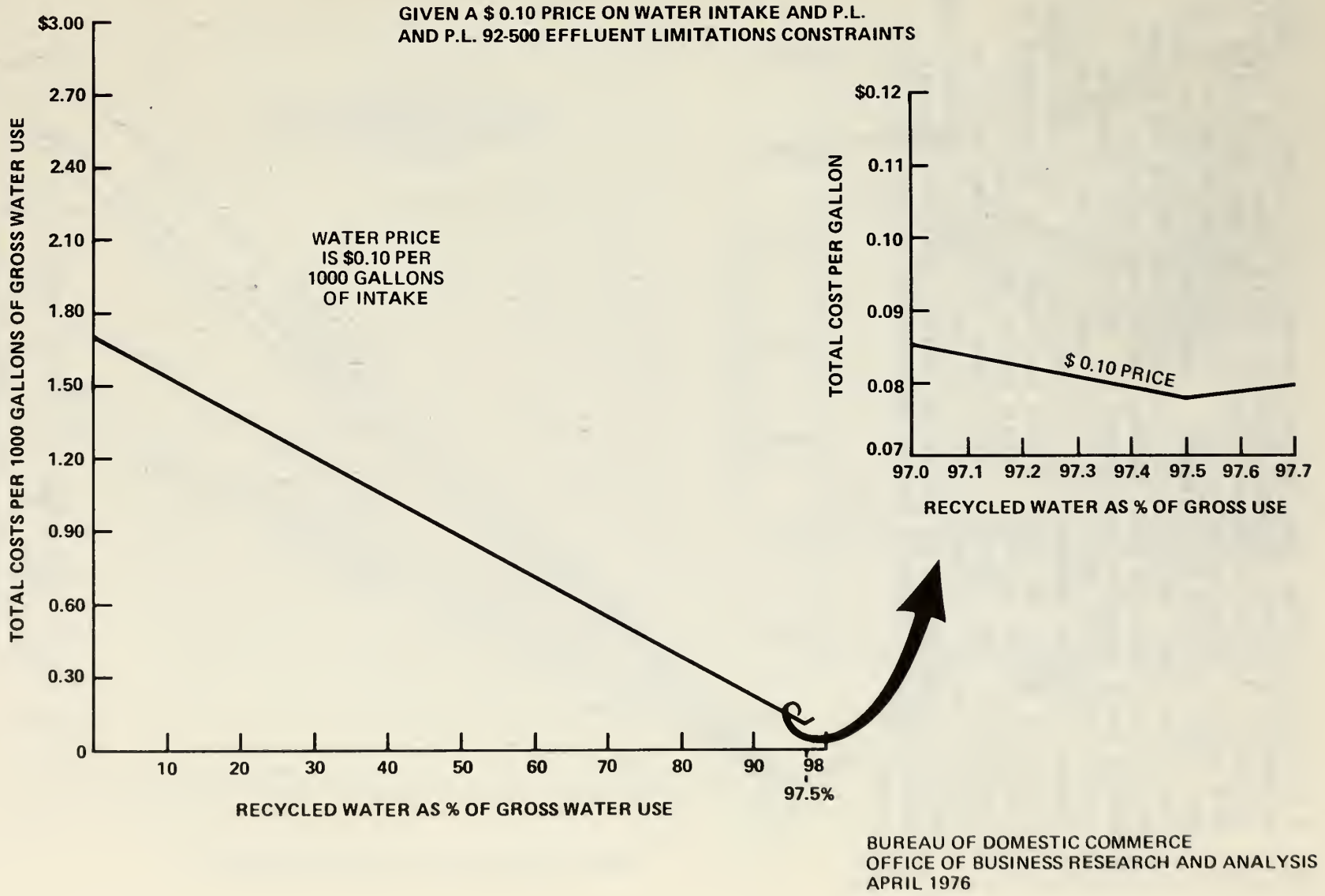
The fourth equation calculated the costs of treating wastewater to meet pollution control standards regulating discharges. The cost of this treatment ranges from $1.33 to $1.45 per 1000 gallons of water discharged. The lower per unit costs are incurred in those cases were there is little recycling and thus larger volumes of water discharged.

The value for r is derived from a split function, in which the per-unit costs of recycling are small up to 975 gallons per 1000 gallons of gross water used, but are very high beyond 975 gallons. This corresponds to the real life situation in which water leaving the cooling tower can be recycled at moderate cost up to the point where dissolved solids concentrations become critical. In the low range of recycling the major costs are pumping and conditioning the water in the recirculating system. Beyond the point where dissolved solids exceed tolerable levels, it becomes necessary to use expensive sidestream treatment to remove dissolved solids.

The sixth equation brings together all the cost and volume relationships to calculate the total water-related costs per 1000 gallons of gross water used. The first expression (Ip) calculates the payments that would be paid for raw water under a water pricing policy. The second expression (Ii) calculates the costs of pumping and treating the intake. The third expression (1000x4¢) calculated general water use costs such as cooling tower operation and laboratory costs that are incurred regardless of the degree of recycling practiced. The fourth expression (Rr) calculates the costs of pumping and treating recycled water. The fifth expression (Dd) calculates the costs of treating discharges. These costs are summed and divided by 1000 to yield a weighted average for total costs per 1000 gallons.

To obtain the desired output, a price should be selected and substituted for p. The computer will then work through the model for a range of values for R. A curve can be developed for the values TWC which are generated. Figure 3 shows the cost curve which is generated if a price of $.10 per 1000 gallons is charged for withdrawals. The lowest point on the cost curve is where 97.5% of gross water used is recycled. It is cheaper to recycle water up to this level than it is to discharge wastewater and obtain new make-up water. It is difficult to recycle beyond 97.5% of gross water use, because dissolved solids build up to unacceptable levels and would have to be removed by expensive means. Under these conditions it would be cheaper to pay the $0.10 price for make-up water (and incur other costs of course) than it is to recycle beyond 97.5%.

Figure 3. **Cost-Effectiveness Of Cooling Water Recycling**



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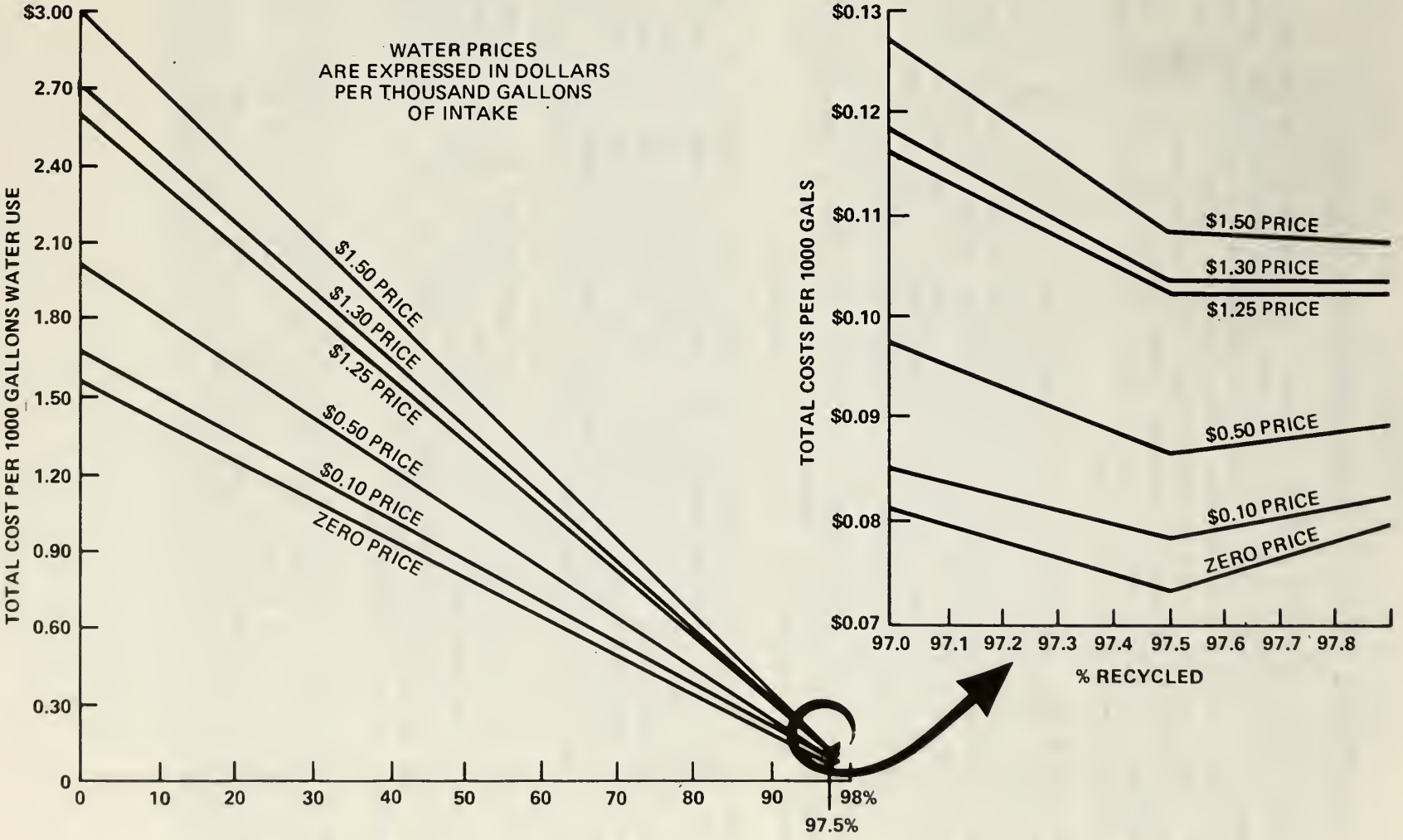
A range of prices can be run through the model to generate a family of cost curves showing their impact on reducing intake. Figure 4 shows a family of curves generated by the model, with water prices ranging from zero to $1.50 per 1000 gallons of intake. The zero price curve shows that the plant would have recirculated 97.5% of gross water use even in the absence of water pricing. This would have been necessitated by other cost factors. Prices in the range of $0.10 to $0.50 per 1000 gallons would not induce further recycling, but would only increase costs. Costs of $0.75 or more would increase the percentage of recycled water to 98%. This would approximate zero discharge. No further reductions in intake could be brought about by recycling. In this closed system intake would be equal to 2% of gross water use, the amount necessary to replace water evaporated in the cooling tower.

Figure 4. **Cost Effectiveness Of Cooling Water Recycling Under P.L. 92-500 Effluent Limitations Constraints**



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APPENDIX B

Non-Contact Cooling System Technical Information

In industrial non-contact cooling, the cooling water becomes heated by 5 to 50 degrees Fahrenheit during use. The smallest temperature rises are associated with air conditioning while the highest temperature rises are generally in cooling of process equipment and materials. The hypothetical example assumes that the cooling water is heated by 20°F, which is typical of many manufacturing non-contact cooling uses.

The use of non-contact cooling water can be on a once-through basis or a recirculating basis. Because of water pollution control limitations on the discharge of heated effluents, and resource limitations, once-through cooling will be uncommon in the future. Recirculating cooling systems, which are already widespread, will become the common method employed in industrial cooling.

Recirculating non-contact cooling systems generally employ evaporative cooling towers in which a fraction of the water evaporates to cool the remainder.

The heat capacity of water is such that a change of one Btu (British thermal unit) in the energy level of one pound of water results in a change of one degree Fahrenheit in the temperature of the water. To evaporate one pound of water, approximately 1000 Btu's per pound must be absorbed by the water. In an evaporative cooling tower, the heat required for evaporation is taken from the heated circulating water, which is sprayed into a draft of air. If the circulating water is cooled 20°F, each pound of water gives up 20 Btu's to the evaporation cycle, and 50 pounds of water provide enough heat to produce a pound of vapor. Thus, in an induced draft cooling tower that reduces the temperature of the water 20°F, one-fiftieth, or 2% of the circulating water is evaporated.

Recirculating systems introduce a number of engineering problems that are not as common in once-through cooling. A sophisticated approach to water conditioning and control must be taken to minimize corrosion, scaling, and biological growths in the system. This requires careful monitoring of the temperature and chemical composition of

the recirculating water, and the use of conditioning chemicals and biocides. Control of dissolved solids concentration, which is described in the next paragraph, requires additional efforts. Any water which is discharged from the plant must receive advanced treatment for removal of the conditioning chemicals, many of which are toxic, and the treatment employed is high in cost per unit volume.

A major engineering problem encountered in recirculating cooling systems is the build-up of dissolved solids in the recirculating water, since the water that evaporates leaves its dissolved solids behind. If the concentration becomes too great, corrosion and scaling can damage heat exchangers, pipes, equipment, and cooling towers. These dissolved solids must therefore be removed by demineralization or by discharging a portion of the recirculating water. Demineralization is expensive and generally would not be employed. Instead, "blowdown" discharges would be used to control dissolved solids concentration. This exerpt from the Betz Handbook of Industrial Water Conditioning provides an excellent discussion of the derivation of blowdown requirements for a non-contact cooling system:

"To avoid such an oversaturation with dissolved mineral solids, it is necessary to limit cycles of concentration. By thus limiting the concentration of the circulating water, the degree of oversaturation can be restricted to within the effective range of the treatment employed. Where the natural windage loss is insufficient to limit cycles of concentration, it is necessary to supplement the windage loss by means of blowdown.

"Blowdown consists in removing a portion of the concentrated circulating water and replacing it with fresh makeup water, thus securing a lowering of the concentration in the system. Blowdown can be either intermittent or continuous. Continuous blowdown is preferred, controlled by a flow control valve on a separate line to waste. The blowdown valve control setting is varied to maintain cycles of concentration within safe limits to prevent scale formation.

"The amount of blowdown required to limit cycles to any predetermined value can be calculated through the use of the basic formula:

$$\text{Cycles of Concentration} = \frac{\% E + \% B}{\% B}$$

where % E = Evaporation loss, expressed as percent of circulation rate.

% B = Combined windage and blowdown loss, expressed as percent of circulation rate.

"While this formula has been expressed in percentages, other units can be used provided all quantities are expressed in the same units. The formula may also be rearranged to solve directly for blowdown as follows:

$$\% B = \frac{\% E}{(\text{Cycles} - 1)}$$

In the hypothetical system it was assumed that the dissolved solids build-up could be allowed to reach a level of 5.0 cycles of concentration. Since the evaporative losses are 2.0%, the blowdown necessary to maintain equilibrium at 5.0 cycles are as follows:

$$\% B = \frac{2.0\%}{(5.0 - 1)} = 0.5\%$$

Since modern cooling tower design can reduce "windage" or "drift" losses to less than 0.007 percent of throughput, this factor has not been considered in this study. Another factor which is important in actual practice is the loss of water and dissolved solids due to leaks, which reduce cycles of concentration in the same way as blowdown. The effect of leaks is not considered in this study, because it is assumed that a new plant would be designed free of leaks to ensure that conditioning chemicals do not percolate into groundwater.

Cost estimates for the price/cost sensitivity model of the non-contact cooling system were made by Bureau of Domestic Commerce staff using a variety of sources of information. Costs of cooling tower operation were based on a publication by the Illinois State Water Survey. Costs of intake pumping and treatment were based on cost estimates made by the Environmental Protection Agency and BDC staff. Costs of chromate removal were based on discussions with employees of Betz Environmental Laboratories, manufacturers of such systems. Demineralization costs are based on a study funded by the Environmental Protection Agency. (Publications are listed in the Bibliography).

The cost estimates for each type of treatment include operating and maintenance costs, depreciation, and cost of capital. The cost components are shown in Tables 1 through 5. A major consideration in estimating costs is the effect of inflation. All cost estimates in this study are based on March 1975 price levels. The use of price indexes was necessary to bring cost estimates made by others up to a consistent level. These price indexes were developed by the Environmental Protection Agency.

The price cost sensitivity model uses these cost estimates to calculate total water costs per 1000 gallons of gross water used. Total water costs vary considerably, depending upon the recirculation practices employed, and the model is computerized to quickly estimate a total water cost for any recirculation rate under consideration. The model is also set up to estimate the cost impact of any price charged for water intake. The model can thus make it possible to determine the impact of various water prices in encouraging a reduction in intake by more intensive recycling.

Table 1

COOLING TOWER COSTS

(Water treated = 10,000 gallons per minute)

Installed Cost of Tower =	$161,000	
Interest Expense (at 10% on declining balance)	$8060/year	$24/day
Depreciation (10 year life, zero salvage value)	$16,100/year	$49/day
Power Costs (0.5 kwh per 1000 gal., @2¢ per kwh)		$144/day
Maintenance Expense (same as power costs)		$148/day
Chemicals Costs ($2.35 per hour)		$56/day
Operating Labor ($6.68 per man-hour, 24 man-hours daily)		$160/day
Total Costs per day		$581/day
Total Costs per 1000 gallons (14.4 mgd total daily flow)		$0.040/1000 gal.

NOTE:

1. Costs are based on March 1975 price levels.
2. Source: Water Use and Related Costs with Cooling Towers, Illinois State Water Survey.

Table 2

Costs of Water Treatment for Chromate Removal

(Water treated = 50 gallons per minute)

Installed Cost of System	=	$150,000	
Interest Expense (at 10% on declining balance)		$7,500/year	= $23/day
Depreciation (20 year life, zero salvage value)		$7,500/year	= $23/day
Power Costs (5.75 kw per hour, @2¢ per kwh)			$3/day
Maintenance expense (10% of equipment costs, excluding installation costs)			$18/day
Chemicals Cost (7¢ per 1000 gallons)			$5/day
Operating Labor ($6.68 per manhour, 4 man-hours daily)			$26/day
Total Costs per day			$98/day
Total Costs per 1000 gallons (72,000 gallons total daily flow)			$1.36/1000 gal.

Costs are estimated by BDC, based on discussions with an equipment manufacturer.

Table 3

COSTS OF ION EXCHANGE DEMINERALIZATION

(Water treated = 50 gallons per minute)

Installed Cost of System =	$56,000	
Interest Expense (at 10% on declining balance)	$2,800/yr.	$8/day
Depreciation (10 year life, zero salvage value)	$5,600/yr.	$17/day
Power Costs		$1/day
Maintenance expense		$9/day
Chemicals Cost		$19/day
Operating Labor ($6.68 per man-hour, 4 man-hours per day)		$27/day
Replacement Resins		$20/day
Total Costs per day		$101/day
Total Costs per 1000 gallons (72,000 gallons daily flow)		$1.40/1000 gal.

NOTE:

1. Costs are based on March 1975 price levels.
2. Source: Costs estimated by BDC, based on EPA research report Ion Exchange Color and Mineral Removal from Kraft Bleach Wastes, 1973.

TABLE 4

COSTS OF INTAKE WATER TREATMENT

(1 million gallons per day plant)

Construction Costs		
Raw Water Pumping	$117,100	
Sedimentation Basin	89,400	
Chlorination Feed Systems	40,100	
Total Installed Cost	$246,600	
Expenses		
Interest Expense (at 10% on declining balance)	$12,330/year	$37/day
Depreciation (20 year life, zero salvage value)	$12,330/year	$37/day
Labor ($6.68 per man-hour, 3.5 man-hours daily)		$24/day
Electric Power Costs (0.3 kwh per 1000 gal., @ 2¢ per kwh)		$6/day
Chemicals (119 lbs per day)		$14/day
Maintenance Materials (1% per year)		$7/day
Total Costs per day		$126/day
Total Costs per 1000 gallons		$0.126/1000 gal.

NOTE:

1. Costs are based on March 1975 price levels.
2. SOURCE: Costs estimated by BDC, based on unpublished material provided by the U.S. Environmental Protection Agency and the U.S. Department of the Interior.

TABLE 5

Costs of Intake Water Treatment

(10 million gallons per day plant)

Construction Costs		
Raw Water Pumping	$548,600	
Sedimentation Basin	334,300	
Chlorination Feed System	104,700	
Total Installed Cost	$987,600	
Expenses		
Interest Expense (at 10% on declining balance)	$49,400/yr.	$150/day
Depreciation (20 year life, zero salvage value)	$49,400/yr	$150/day
Labor ($6.68 per man-hour, 8.3 man-hours daily)		$53/day
Electric Power (0.3 kwh per 1000 gal, @ 2¢ per kwh)		$60/day
Chemicals (990 lbs. per day)		$71/day
Maintenance Materials (1% per year)		$30/day
Total Costs per day		$514/day
Total Costs per 1000 gallons		$0.051/1000 gal

NOTE:

1. Costs are based on March 1975 price levels.
2. SOURCE: Costs estimated by BDC, based on unpublished material provided by the U.S. Environmental Protection Agency and the U.S. Department of the Interior.

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GLOSSARY OF INDUSTRIAL WATER USE TERMS

Blowdown - is water discharged from a recirculating water system in order to prevent dissolved solids content of the recirculating water from building up to undesirable levels. The concentrated water in the blowdown is replaced with make-up water, to maintain the system's water volume at acceptable dissolved solids concentration.

Boiler Feedwater - is the make-up water used for all steam generating purposes at the plant. It does not include the quantity of steam condensate returned to boilers.

Cascading - is the practice of reusing the wastewater from one operation as the input water for another operation which has a lower water quality requirement.

Color, Taste and Odor Control - refers to treatment of fresh intake water with activated carbon or charcoal or other methods, to remove or reduce color, taste, odor or other trace contaminants.

Company Water System - a company-owned water system supplying water for its own use or to another company but whose primary purpose is not to supply water to the general public or other industrial users.

Consumption (Depletion) - is the loss of water through use in the plant and is measured indirectly as the difference between the volumes of water intake and water discharge. It is the result primarily of evaporative losses, but includes water incorporated into product, seepage from holding ponds, water consumed by personnel, and similar unaccounted losses. It is representative of a depletion of a water resource to the extent that the water consumed may be transferred out of a particular watershed and to the extent that the water may be relocated to the vapor phase of the hydrologic cycle. It is water that is not immediately available for planning reuse.

Consumption Rate - is the ratio of Consumption to Gross Water Use. This ratio indicates the fraction of gross water throughput that is consumed by the manufacturer.

Contact Cooling Water - is water used to remove heat from process materials, products, or equipment by water sprays, flooding, quenching in baths, or other direct contact of water with the materials.

Cycles of Concentration - refers to the build-up of dissolved solids in recirculating steam or water system. The cycles of concentration is the ratio of the dissolved solids concentration in the recirculating water to the dissolved solids concentration in the make-up water.

Demineralization - is the process of removing dissolved inorganic solids from water. Demineralization techniques include ion-exchange, reverse osmosis, distillation, and electrodialysis.

Dissolved Solids - are compounds that are dissolved in water, as distinct from suspended solids which are not actually in solution. Generally dissolved solids are salts of calcium, magnesium, and sodium. Other common dissolved solids are silica, phosphates, heavy metal compounds, and organic complexes.

Dissolved Solids Control - refers to treatment of water for control of dissolved solids content or character by (a) SOFTENING, by hot or cold lime-soda process or ion-exchanger by (b) DEMINERALIZATION, through cation-anion exchange resins, distillation, reverse osmosis or other means. It does not include water that was demineralized for use in laboratories or small pilot plants.

Fume Scrubbing Water - is water used for emmissions-control and/or recovery of materials, products, or by-products contained in gaseous or vapor effluent streams from hoods, stacks, cupulas, towers, etc.

Gross Water Use - represents the estimated quantity of water that would have been required if no water had been recycled or reused in the manufacturing process.

Intake (Withdrawal) - refers to water brought into a manufacturing plant for first-time use in that plant, regardless of its source. It may be fresh or brackish (1000 parts per million total dissolved solids or more), and may include effluents from domestic or industrial wastewater systems that are delivered to the plant to supplement other intakes. It includes waters that are purchased as well as those developed by the plant itself.

Non-Contact Cooling Water - is water used for cooling and condensing through heat exchange surfaces that separate the cooling water from the item that is cooled.

Process Water - is water or steam that comes in contact with the materials being processed or the final product but does not include contact cooling water or steam used for heating or cooking in closed coils or jackets.

Public Water System - a water supply system, publicly or privately owned, whose primary purpose is to supply water to the general public or to industrial users.

Recirculation (Reuse) - refers to the multiple use of intake water within a single establishment in which the water after one use is recycled with or without treatment for the same use, or is channelled to other stages of the plant for use in place of new intake water in a cascade system where water of diminishing quality is acceptable. Recirculation or reuse of water may be a deliberate measure for water conservation or may be a secondary benefit associated with recovery of materials, products, by-products, heat, or pollution control.

Recycling Rate - is the ratio of Gross Water Used to Intake. This ratio indicates the number of times intake water is used before it is discharged or consumed.

Sanitary and Other - is the water used personally by employees, in cafeterias, for building and equipment clean-up, plant grounds maintenance, fire fighting, and other uses.

Suspended Solids Removal - refers to the classification of intake water by settling with or without the addition of chemicals, and by filtration or fine-screening, including that reported under settling if it was followed by this step.

Thermal Power Cooling Water - is water used to condense steam and for other cooling purposes in the steam electric generating facilities that are operated by the plants.

Water Discharged - is water that leaves the plant premises, excluding steam or evaporative losses. It includes the quantity that is discharged from holding ponds, but not the quantity discharged into the holding ponds.

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